

Future Geo Neutrino Experiments

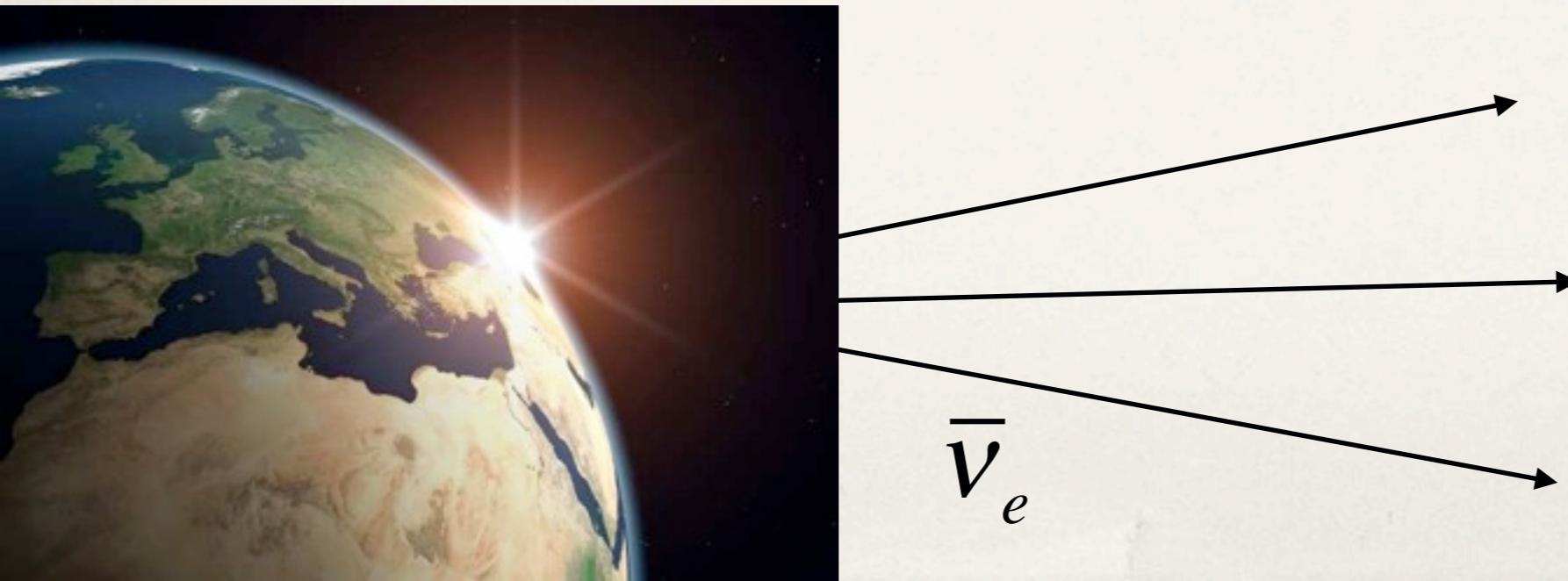
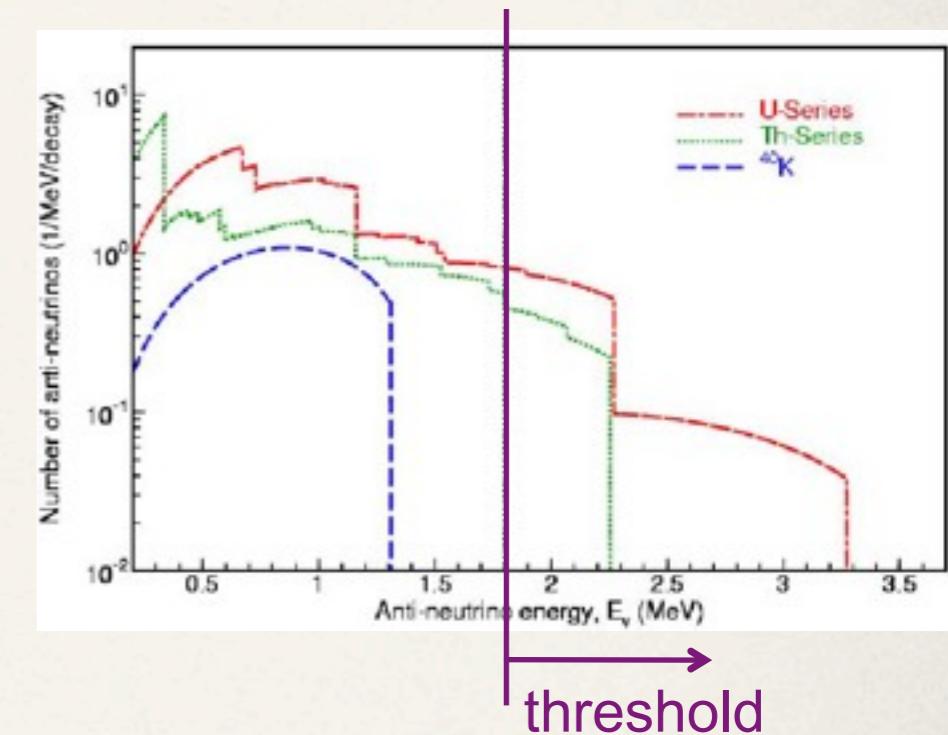
Mark Chen *Queen's University*

Acknowledgments

- * Thanks to S. Dye, J. Learned, Z. Wang, M. Wurm, W. McDonough and O. Šrámek, Y. Huang and the “geo-v Italians” for providing slides, plots I have extracted, and other information for this talk.

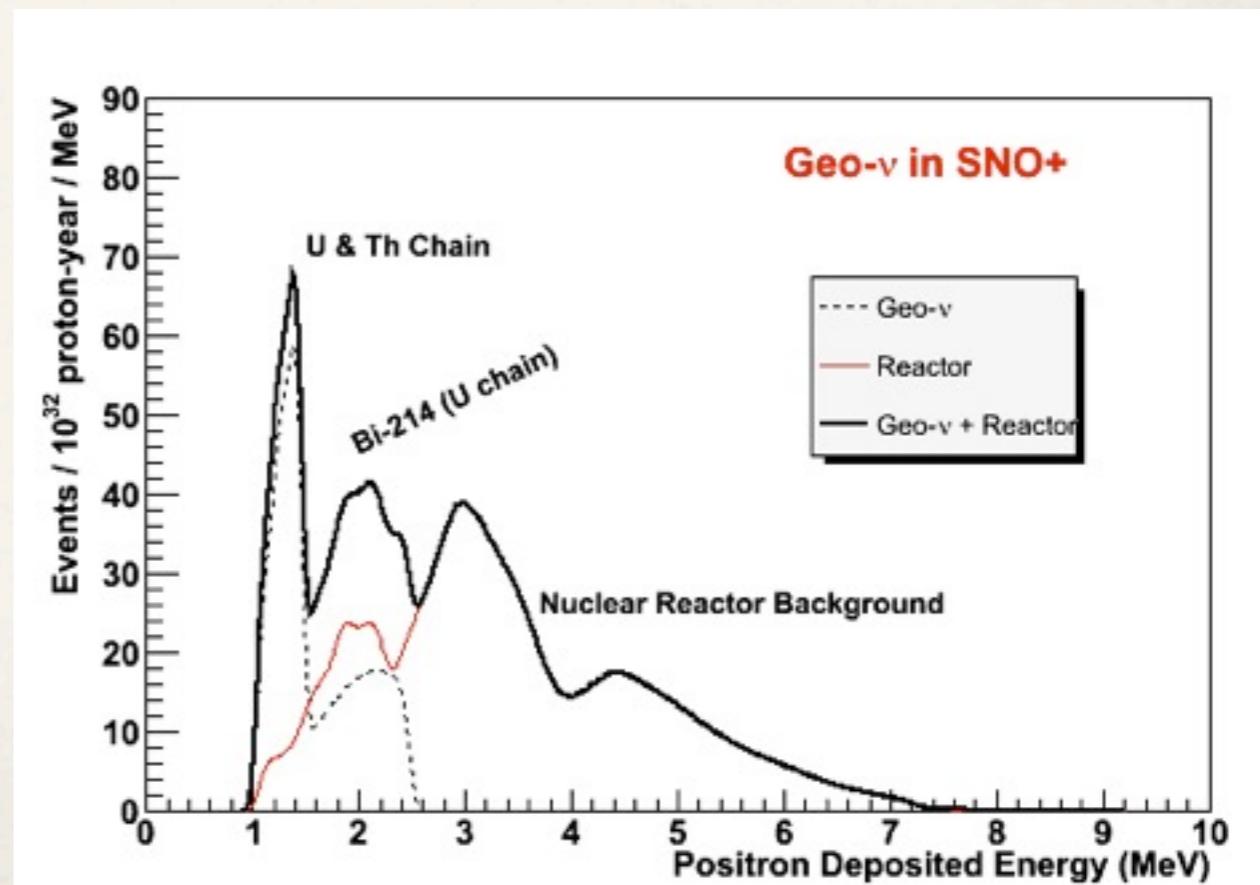
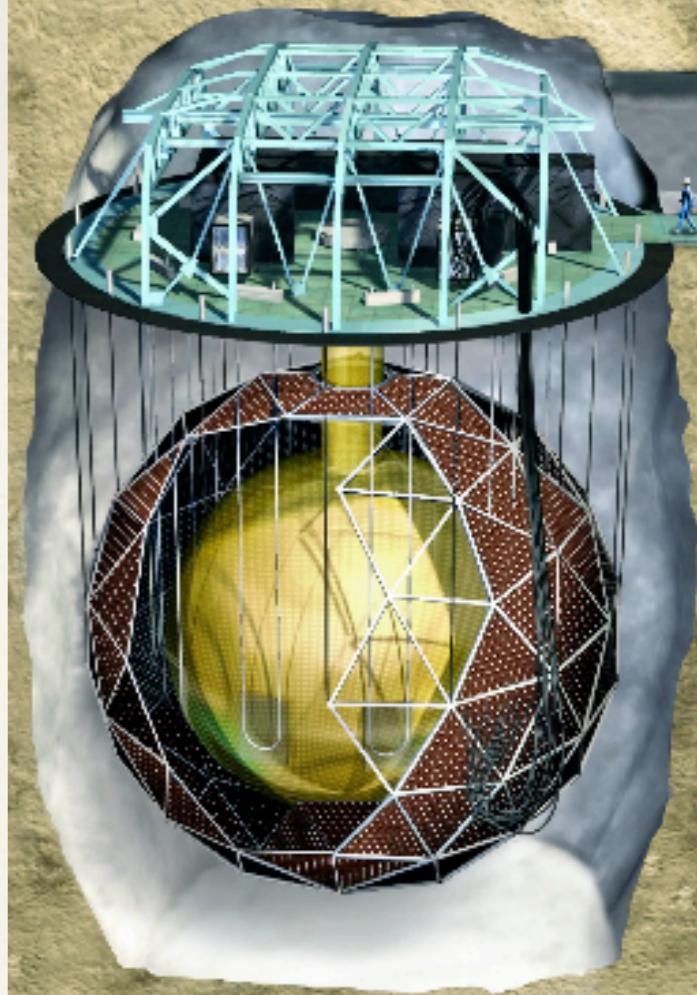
Large Liquid Scintillator Detectors

- ...like KamLAND and Borexino detect
 $\bar{\nu}_e + p \rightarrow e^+ + n$
- new experiments under development and being built include: SNO+, JUNO, RENO-50, Hanohano, LENA



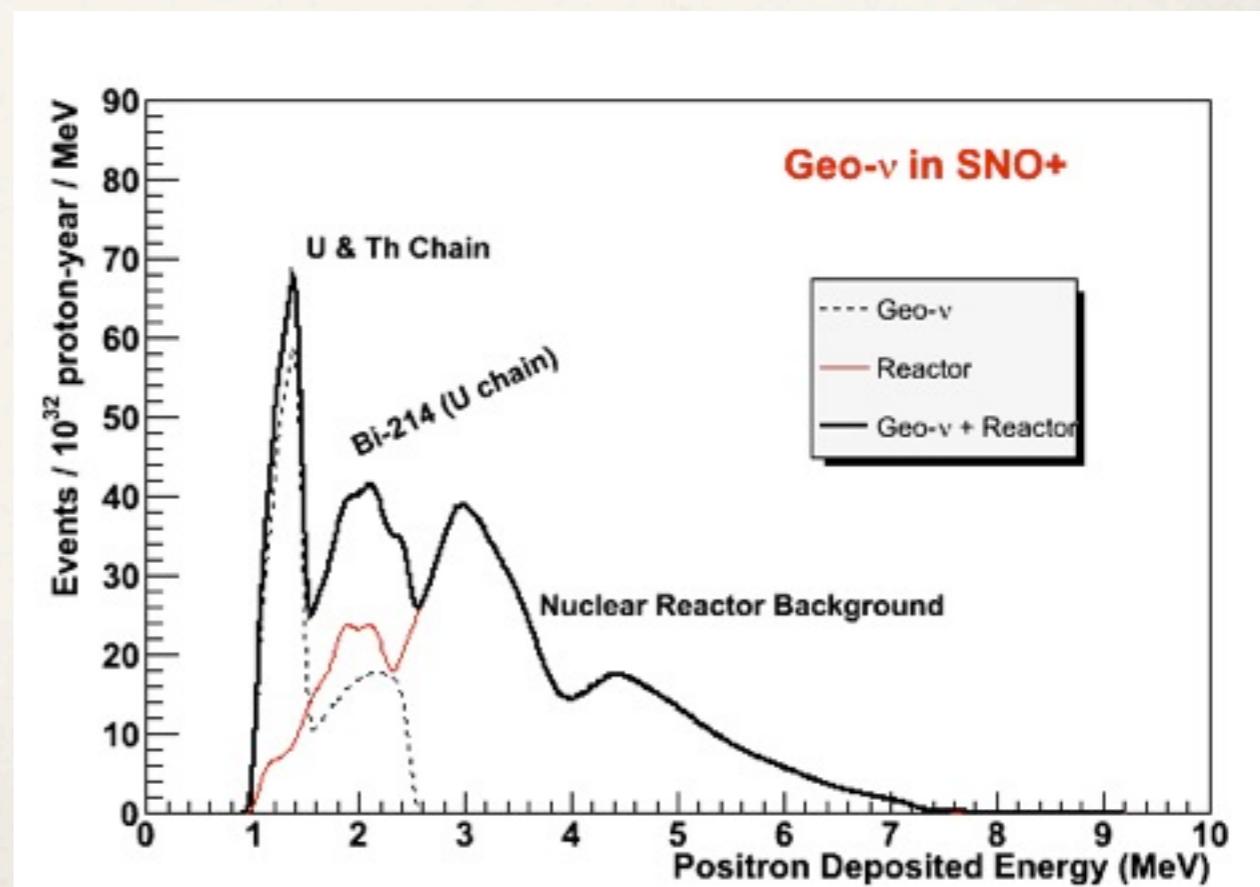
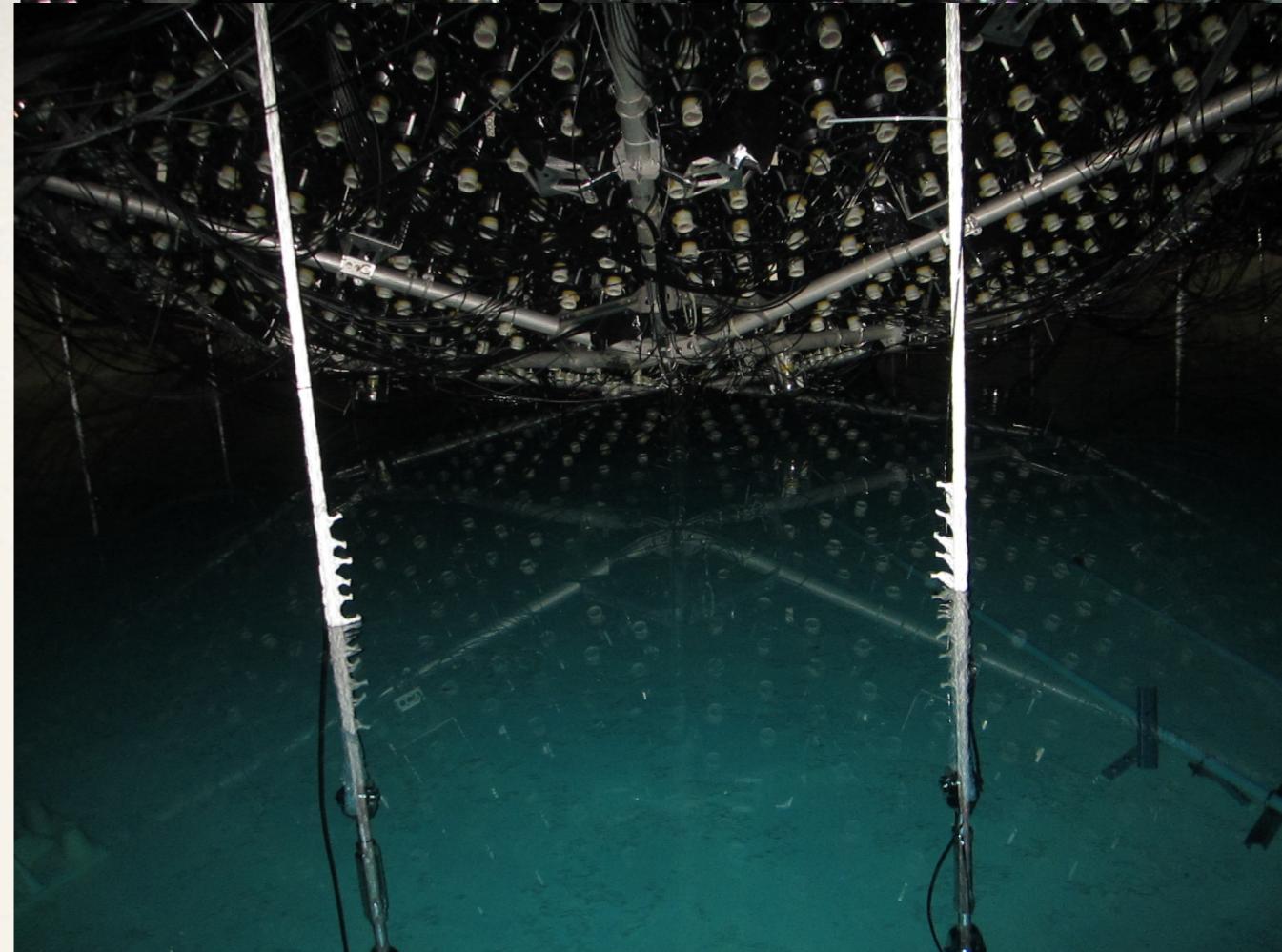
SNO+

- 780 tonnes of linear alkylbenzene-based liquid scintillator
- $50 \text{ TNU} = 29 \text{ geo-}\nu \text{ events per year}$ in SNO+
- geo:reactor = 1:1
- geo neutrino measurement where the local geology is well understood
- reactor neutrino oscillated-spectrum includes peaks and dips (good for measuring Δm^2_{12})



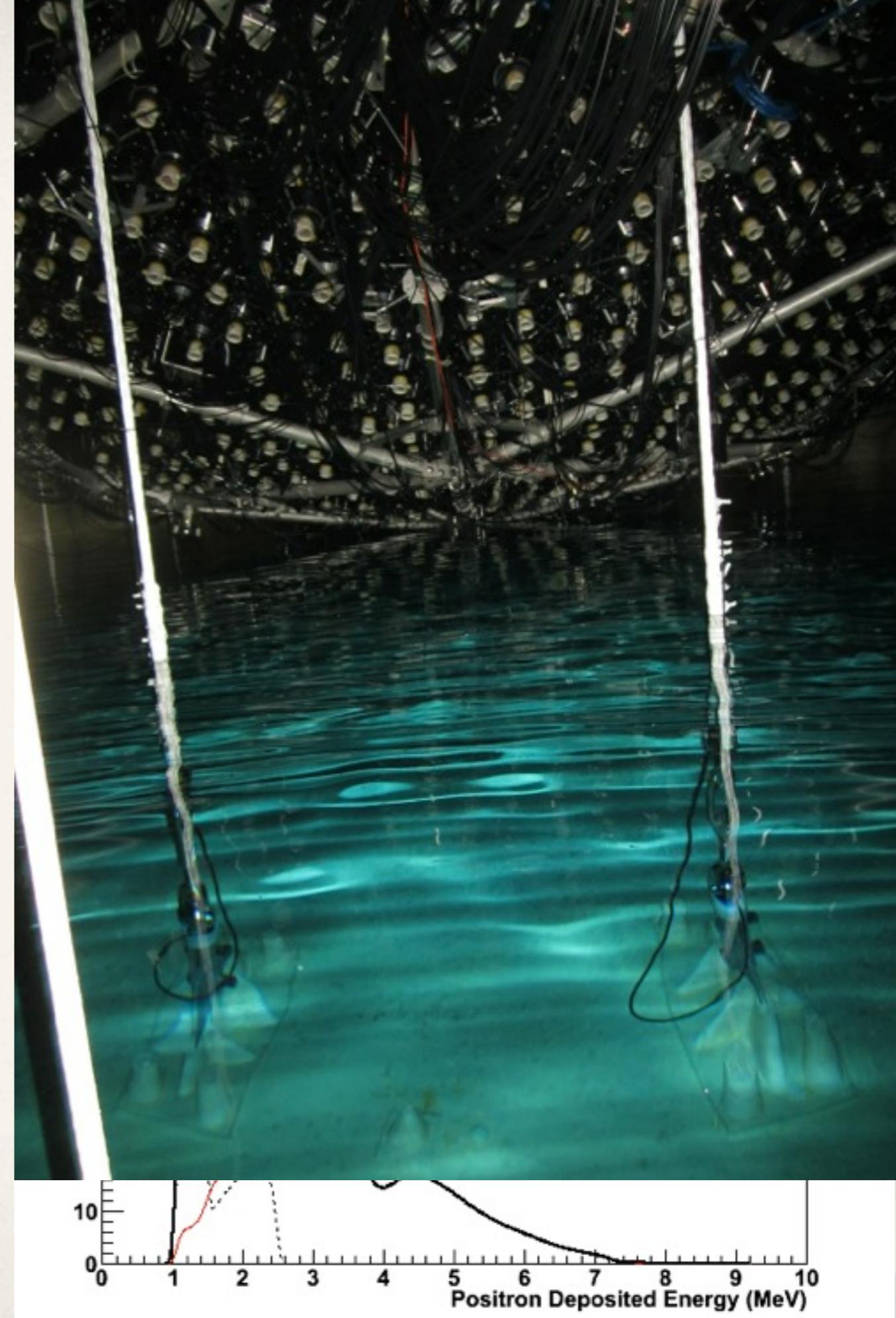
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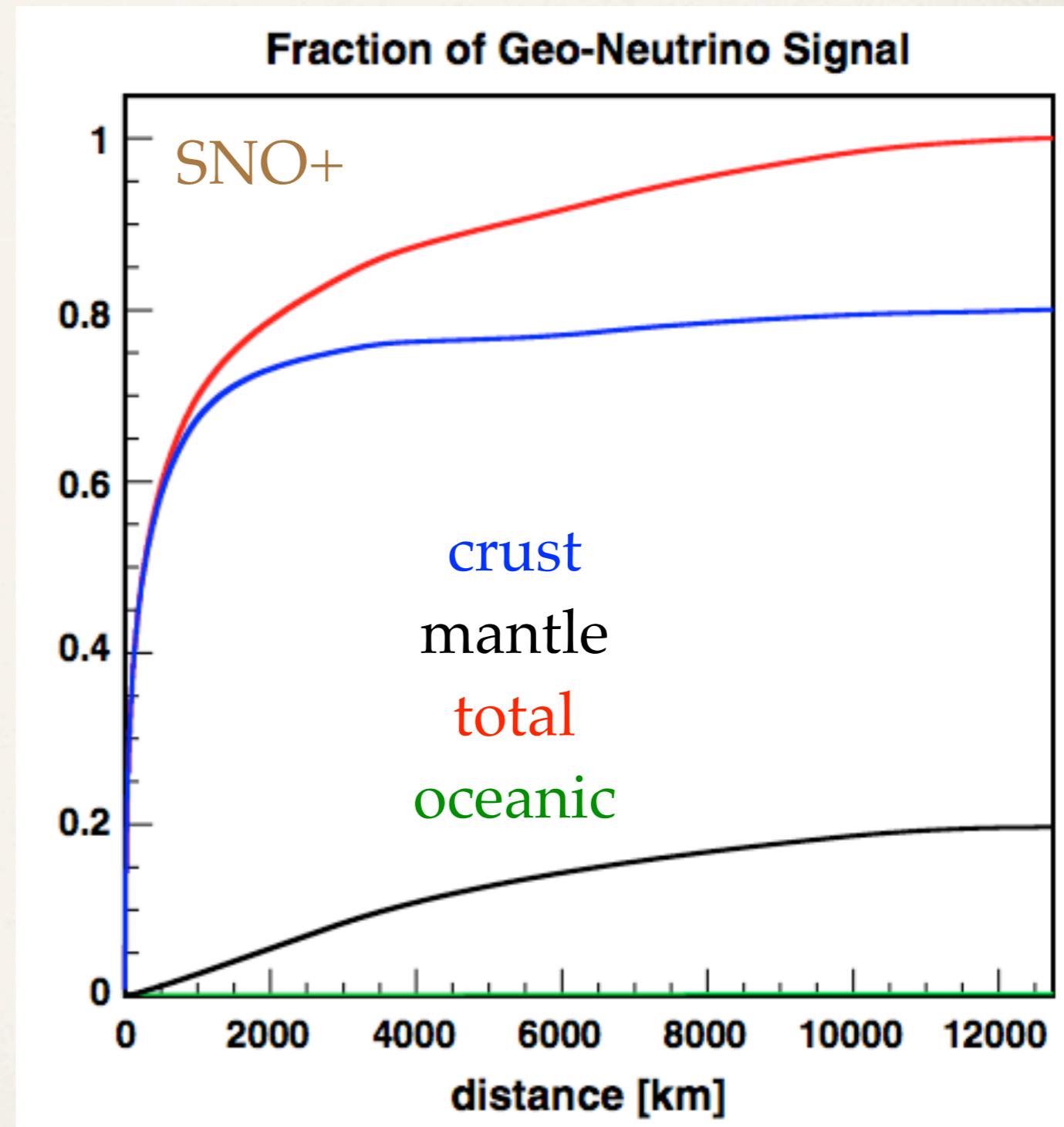
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SNO+ Geo Neutrino Science Flow

1. geo neutrino measurement
2. any local geology impacting interpretation?
3. compare with the dominant main signal component from the surrounding continental crust
4. tests our understanding of the average composition of the continents
5. lastly, subtract off these well-characterized expectations to get the deep Earth component, to test models of global U, Th abundance



“source” of the signal in SNO+ versus distance sampled over

Local Geology around Sudbury

well characterized local geology because of:

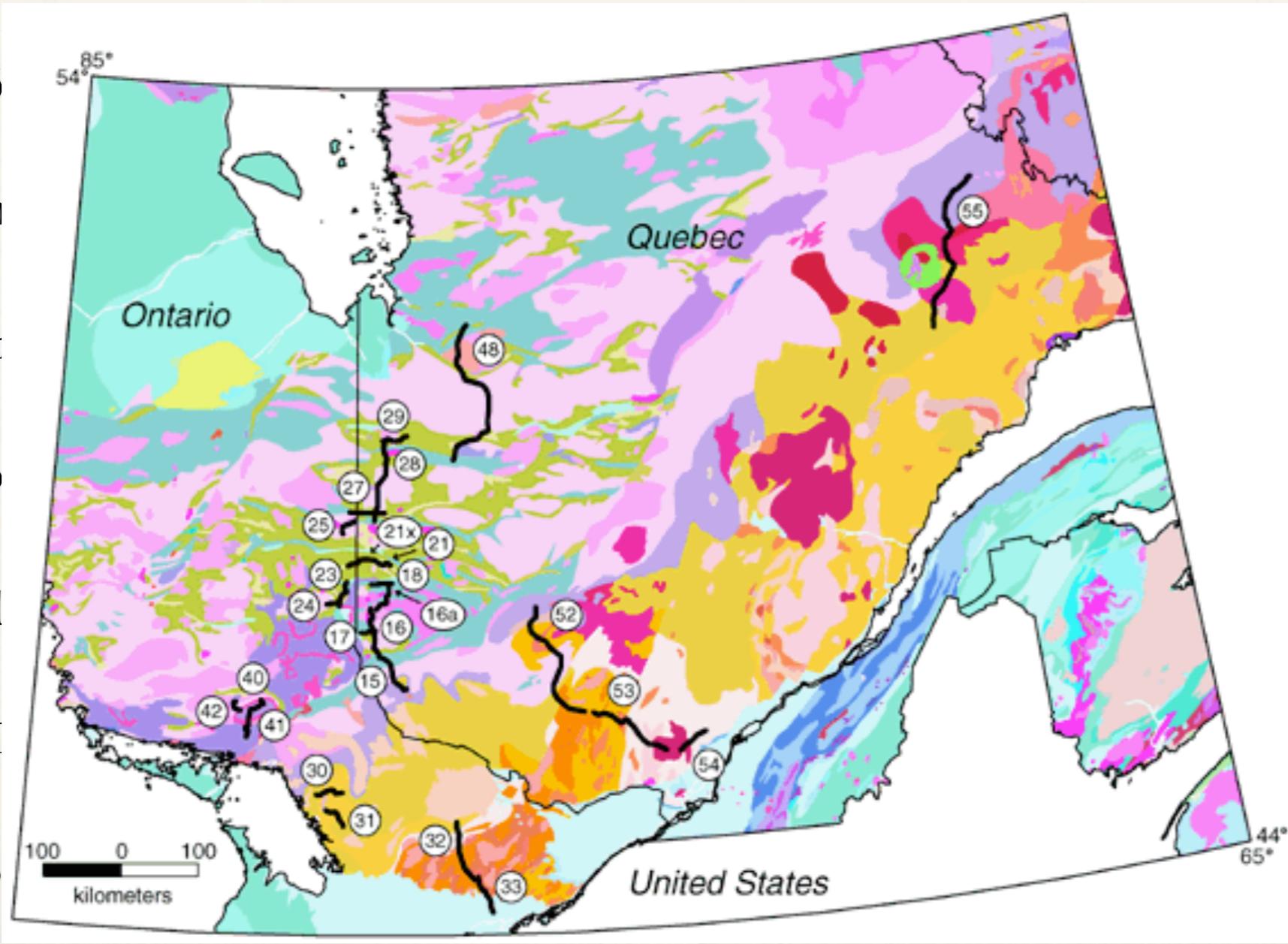
- mining and mineral prospecting in the area
- many deep boreholes (some of the deepest in the world) are nearby
- extensive studies with seismic transects in the vicinity (Lithoprobe)
- heat flow measurements all through the Canadian Shield
- airborne gamma ray maps (uranium prospecting)
- tilted and uplifted continental crust nearby (Kapuskasing)
 - allows some study of the vertical profile to access the lower crust composition
- regional geology studies facilitated because of exposed rocks

Local Geology around Sudbury

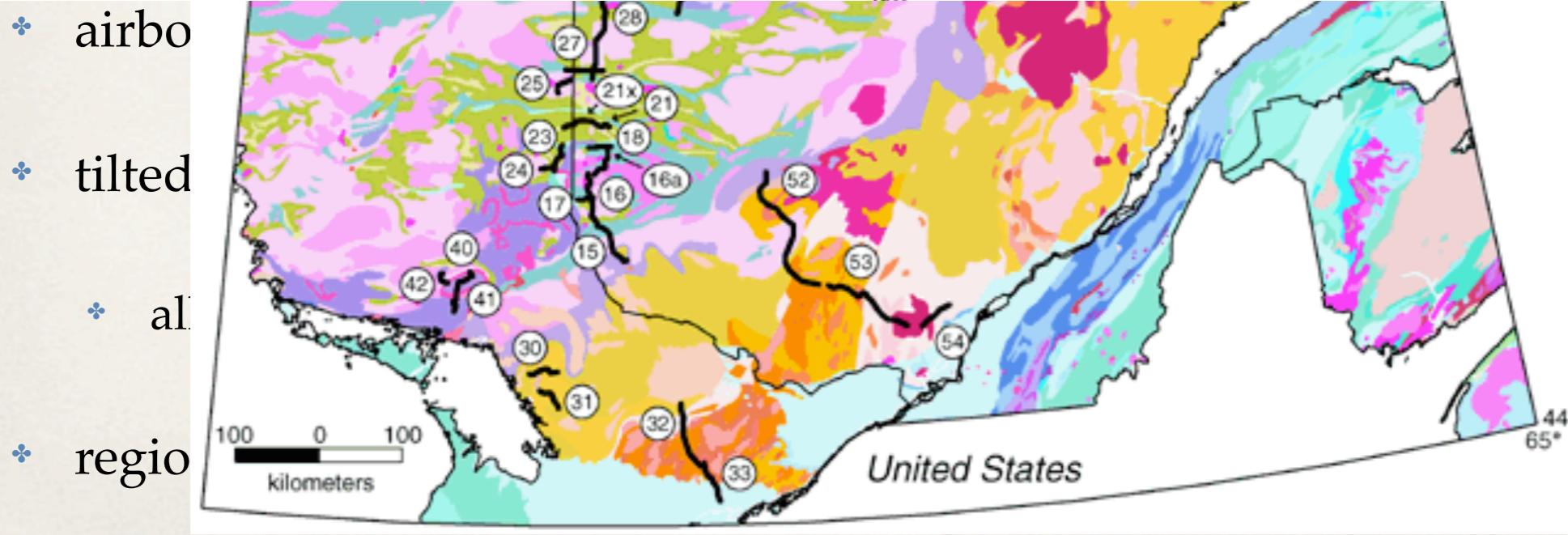
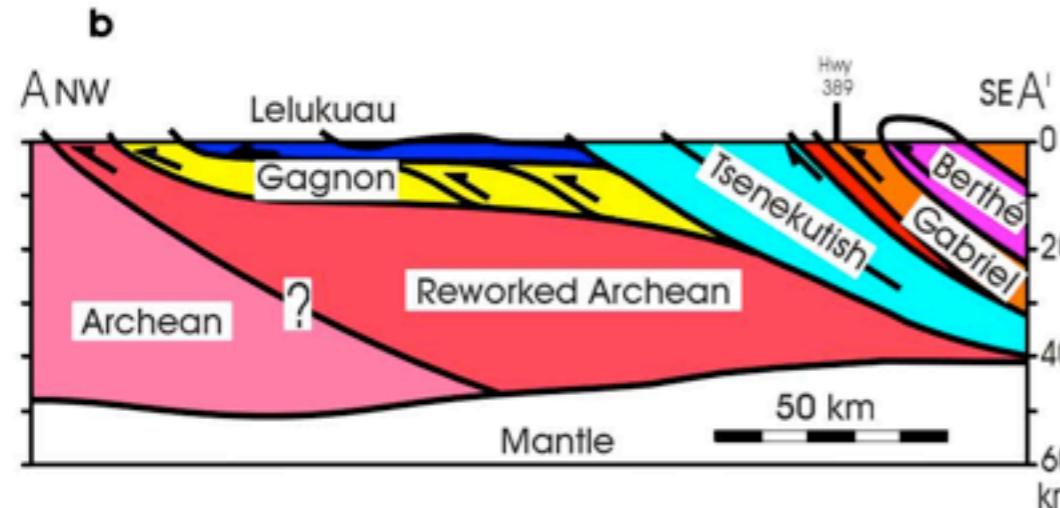
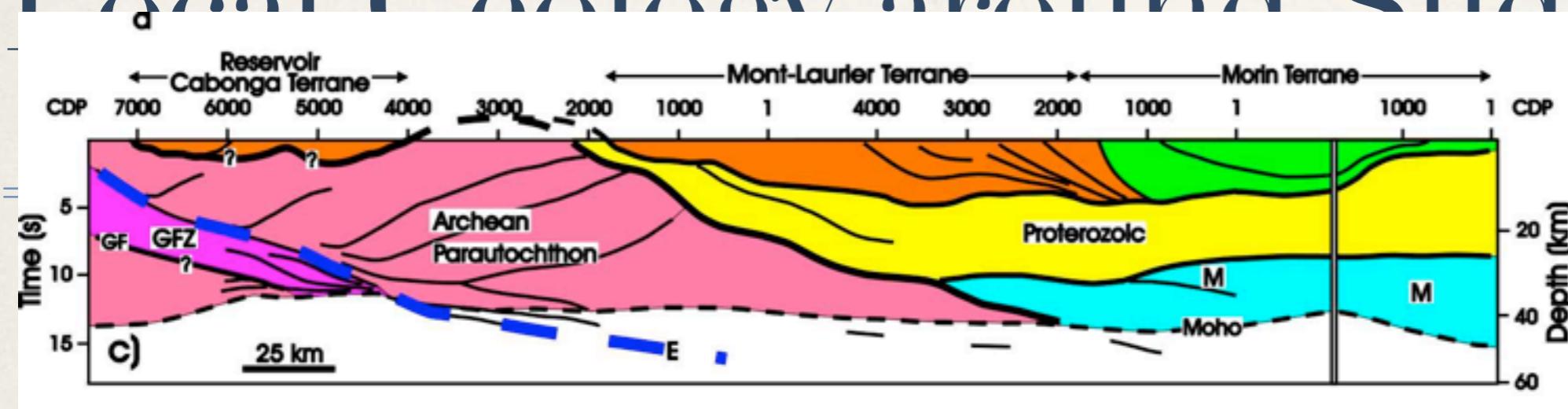
well characterized local geology because of:

- * mining and mineral prospecting in the area

- * many
- * extensive
- * heat
- * airbor
- * tilted
- * alluvial
- * regional



Local Geology around Sudbury

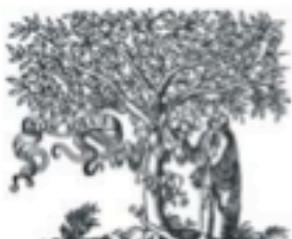


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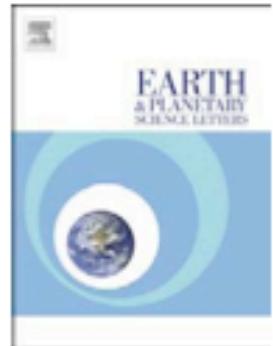
Earth and Planetary Science Letters 288 (2009) 301–308



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journal homepage: www.elsevier.com/locate/epsl



Enhanced crustal geo-neutrino production near the Sudbury Neutrino Observatory, Ontario, Canada

H.K.C. Perry ^a, J.-C. Mareschal ^{a,*}, C. Jaupart ^b

^a GEOTOP-UQAM-McGill, Université du Québec à Montréal, Canada

^b Institut de Physique du Globe de Paris, France

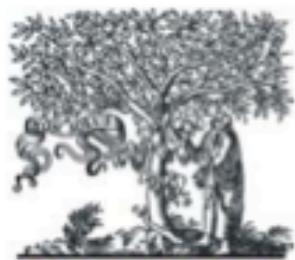
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Earth and Planetary Science Letters 288 (2009) 301–308



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$$\langle Q \rangle_S = 58 \text{ mWm}^{-2}$$

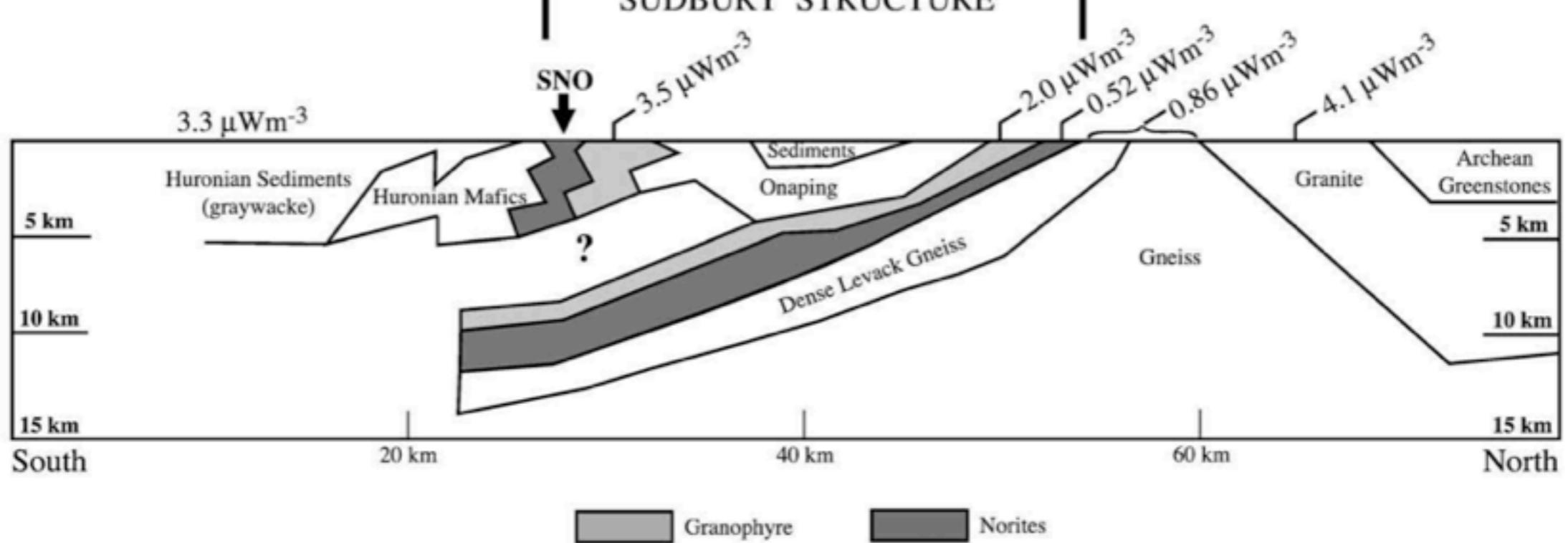
$$\langle Q \rangle_N = 49 \text{ mWm}^{-2}$$

SUDBURY STRUCTURE

Enhanced
Ontario, C

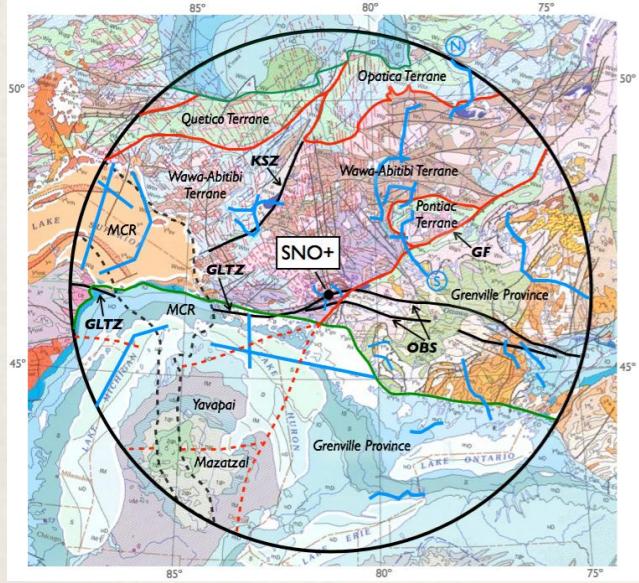
H.K.C. Perry^a

^a GEOTOP-UQAM-McG
^b Institut de Physique



- * regional

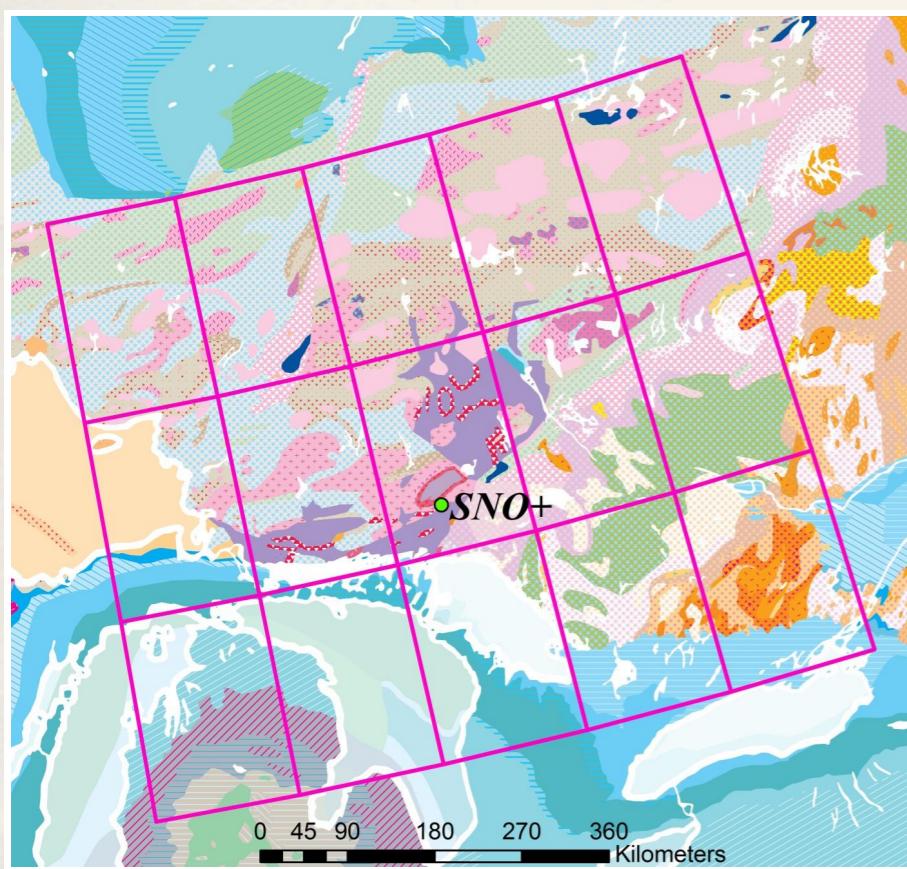
SNO+ Local Geology from Huang et al. work



Northern 60%: ancient Neoarchean to Mesoproterozoic crust; Superior Province (west) & Grenville Province (east)

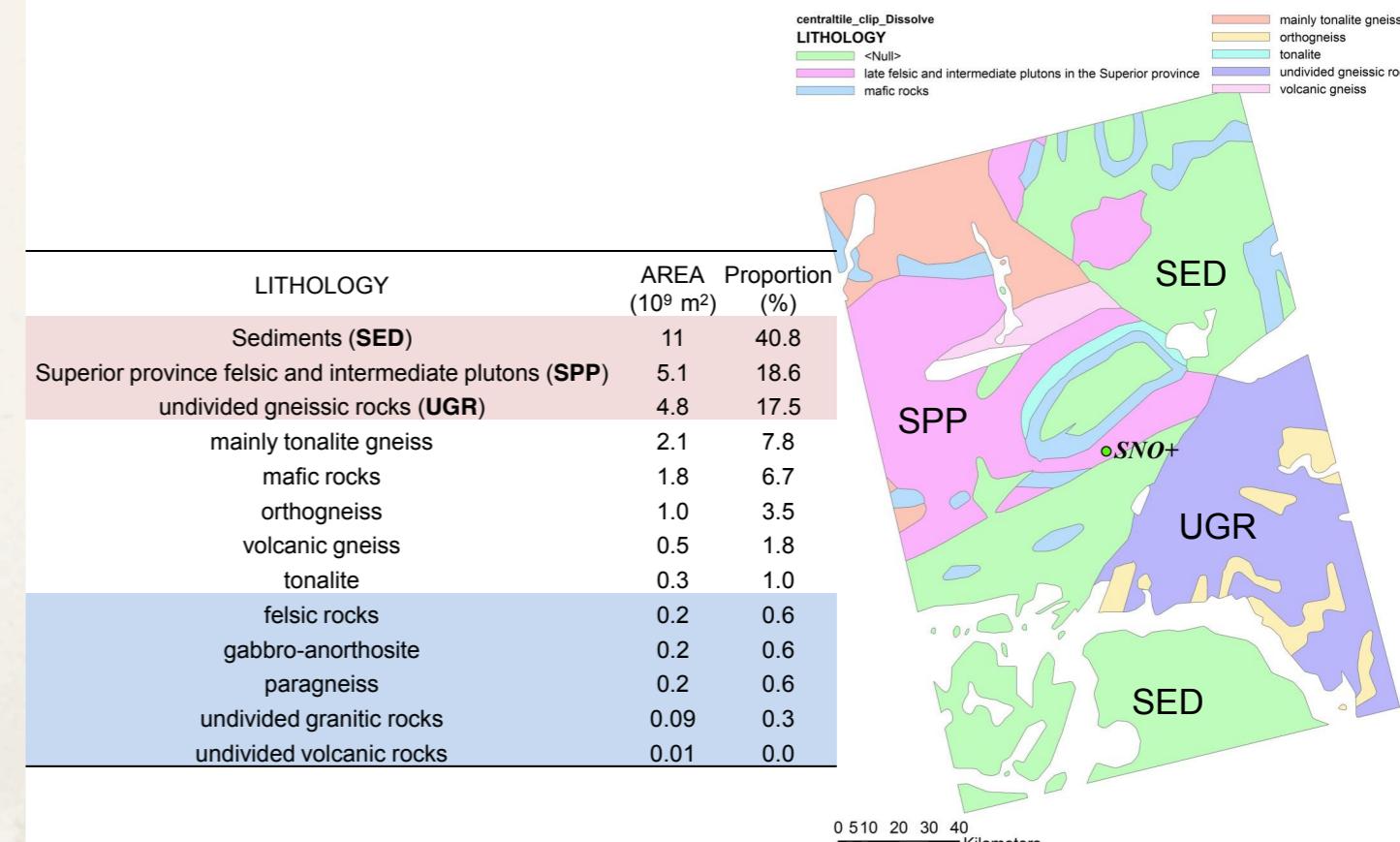
Southern 40%: Paleozoic Sedimentary rocks

Courtesy of Shirey; base map: Reed et al 2005



LITHOLOGY	AREA (10 ⁹ m ²)	Proportion (%)
Sediments (SED)	11	40.8
Superior province felsic and intermediate plutons (SPP)	5.1	18.6
undivided gneissic rocks (UGR)	4.8	17.5
mainly tonalite gneiss	2.1	7.8
mafic rocks	1.8	6.7
orthogneiss	1.0	3.5
volcanic gneiss	0.5	1.8
tonalite	0.3	1.0
felsic rocks	0.2	0.6
gabbro-anorthosite	0.2	0.6
paragneiss	0.2	0.6
undivided granitic rocks	0.09	0.3
undivided volcanic rocks	0.01	0.0

Central Tile Lithology



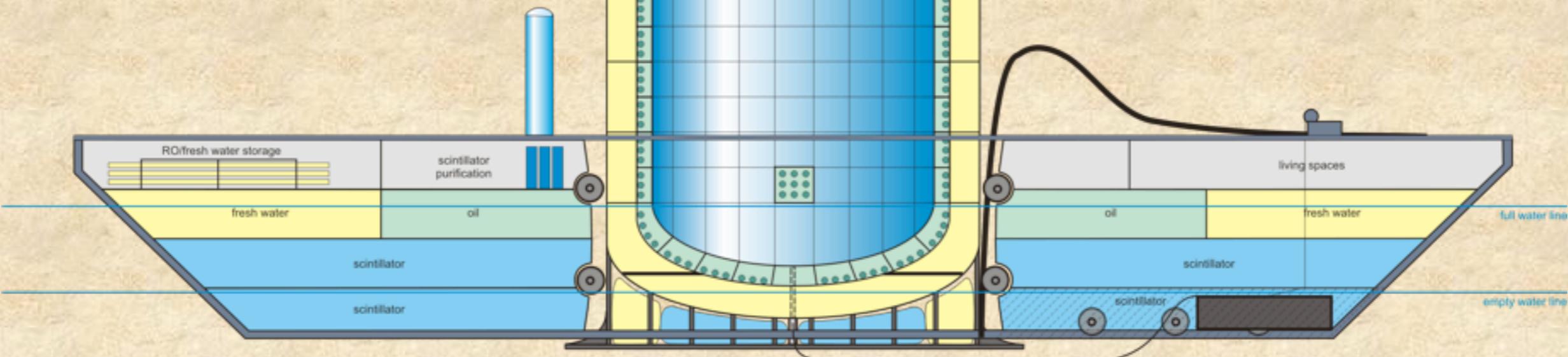
Hanohano a mobile deep ocean detector

Results from DARPA funded study, employing Makai Ocean Engineering for preliminary design and feasibility study.

10 kiloton liquid scintillation

Up to ~100 kt possible

Deploy and retrieve from barge



Measure electron antinus for:

Geophysics

Particle physics (hierarchy, mixing parameters)

Remote reactor monitoring for anti-proliferation.

And lots more science...

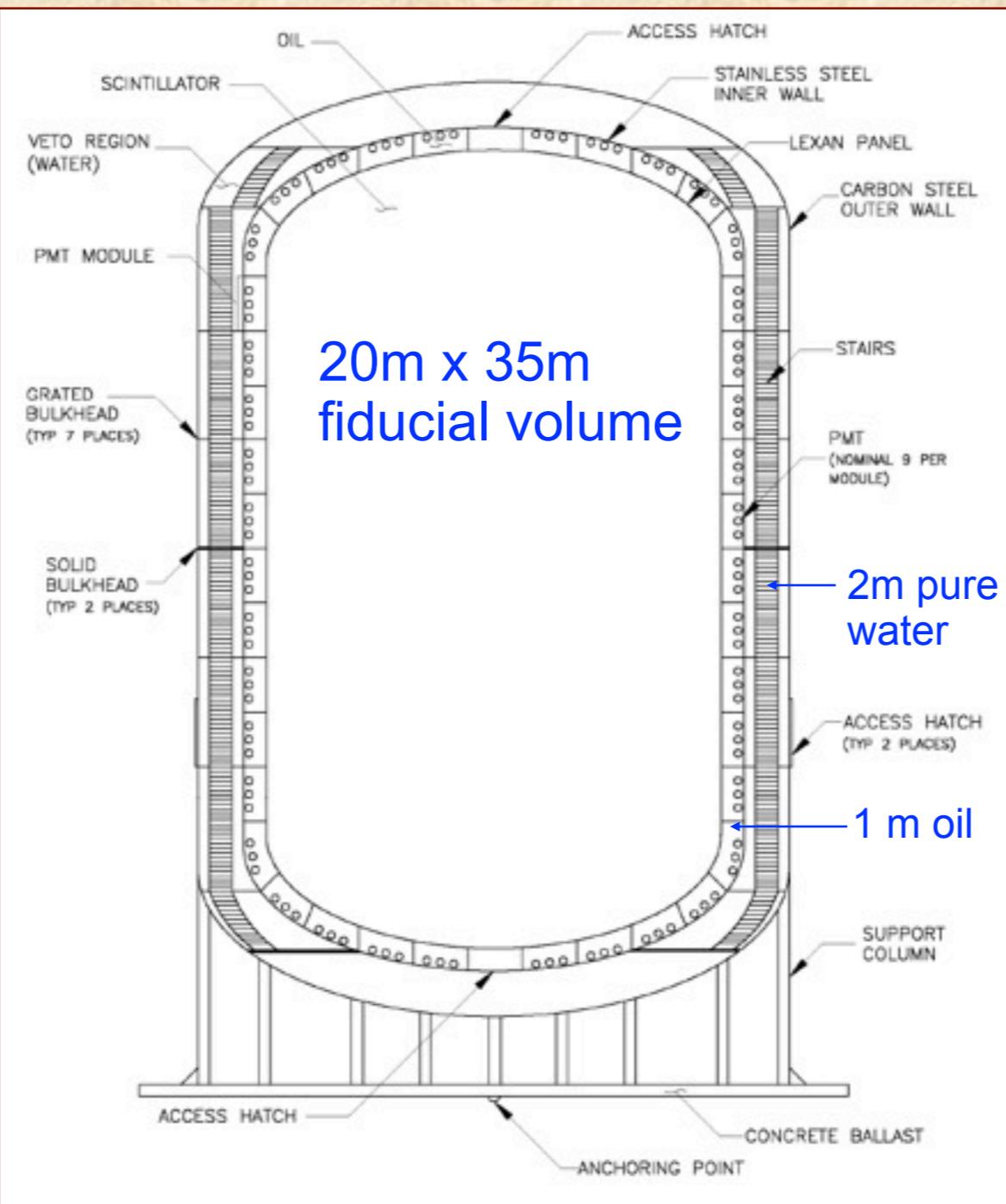
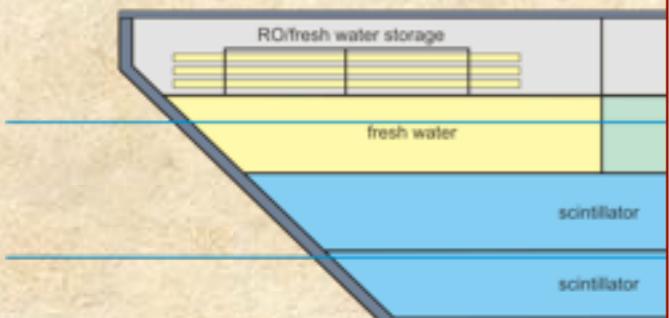
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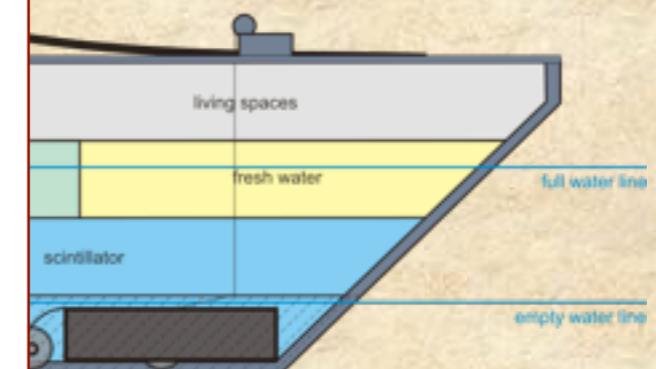
Measure electron antinus for:

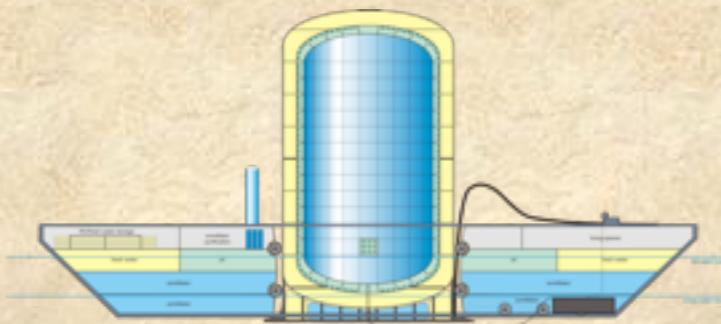
cs

physics (hierarchy, parameters)

reactor monitoring for anti-neutron.

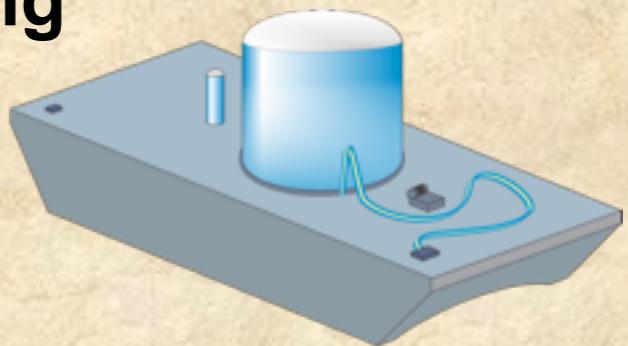
more science...





Hanohano Engineering Studies

Makai Ocean Engineering



Studied vessel design up to 100 kilotons, based upon cost, stability, and construction ease.

Construct in shipyard

Fill/test in port

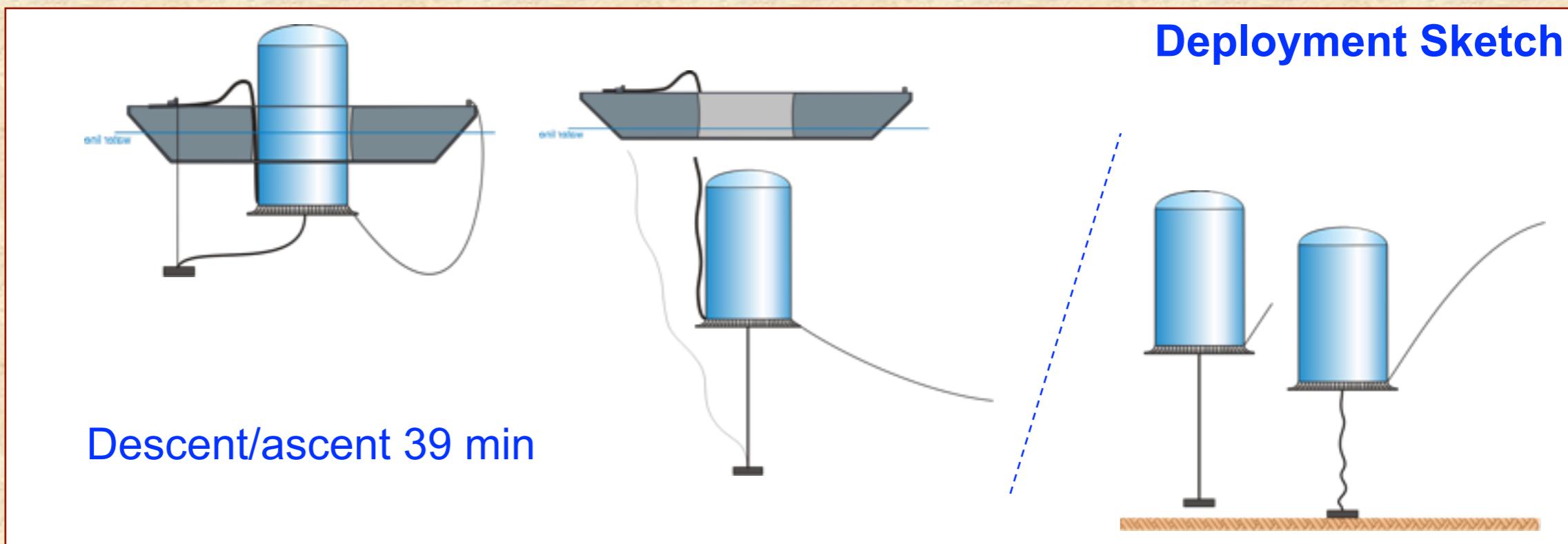
Tow to site, can traverse Panama Canal

Deploy ~4-5 km depth

Recover, repair or relocate, and redeploy



Barge 112 m long x 23.3 wide

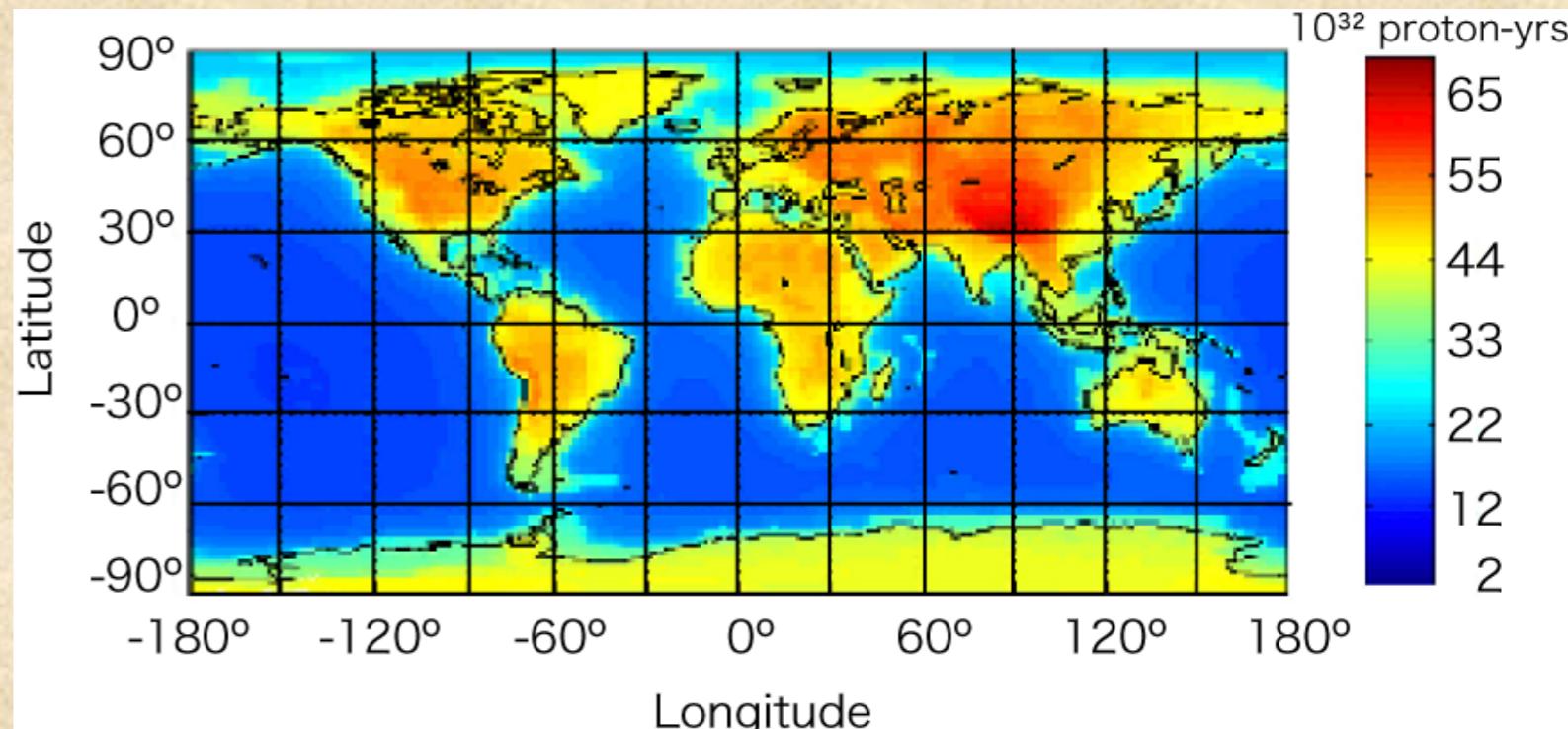


Summary of Expected Results

Hanohano 10 kt-1 yr Exposure

Neutrino Geophysics near Hawaii

79 events per 10 kt-yr



G. Fiorentini, M. Lissia, F. Mantovani, and R. Vannucci, hep-ph/0401085

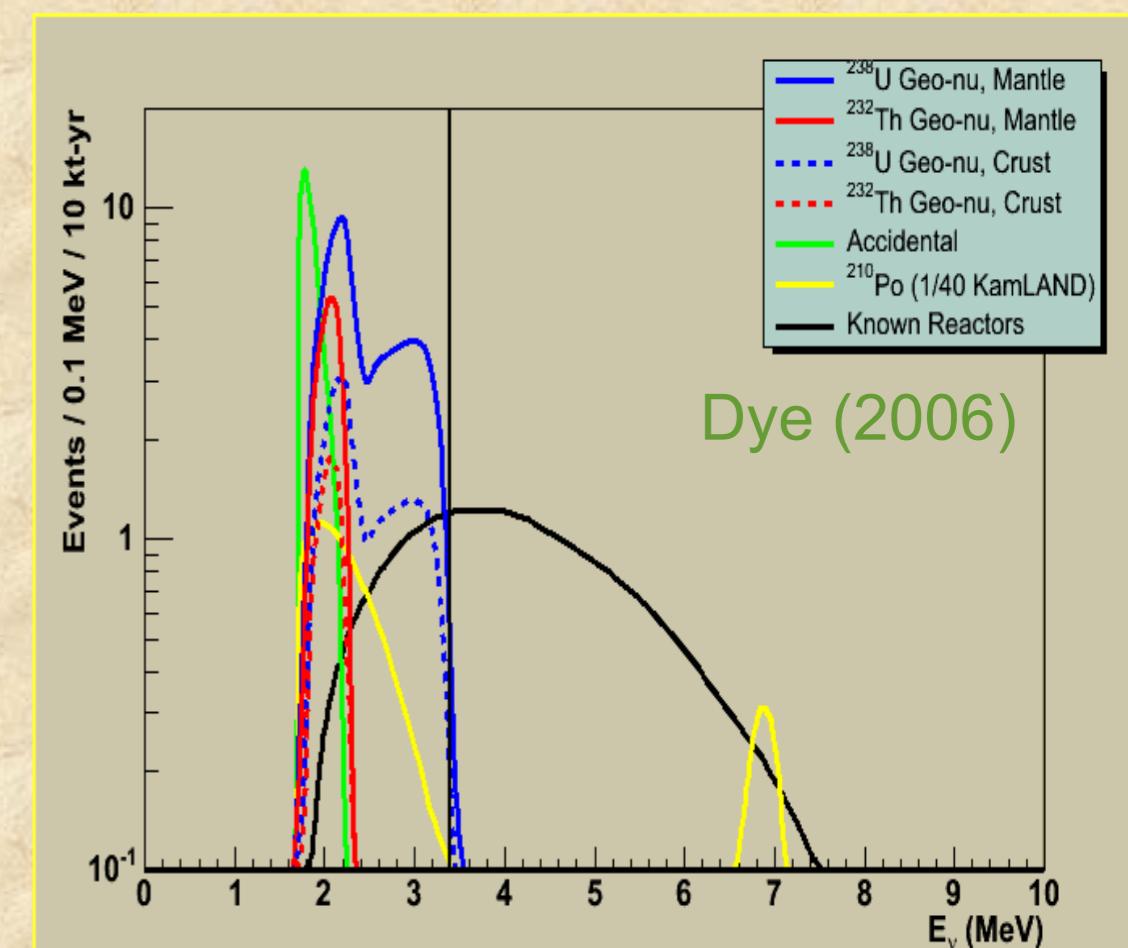
dominated by mantle geo- ν signal

Mantle flux U geo- ν to $\sim 10\%$

Heat flux $\sim 15\%$

Measure Th/U ratio to $\sim 20\%$

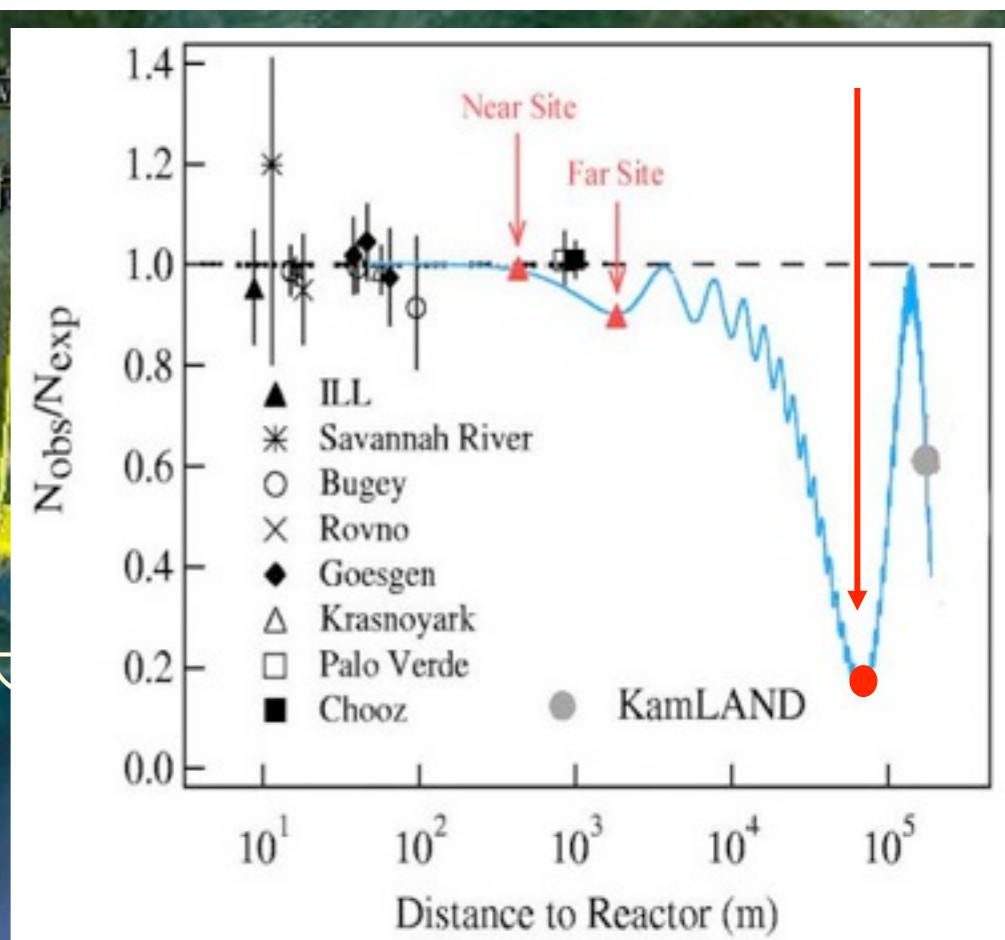
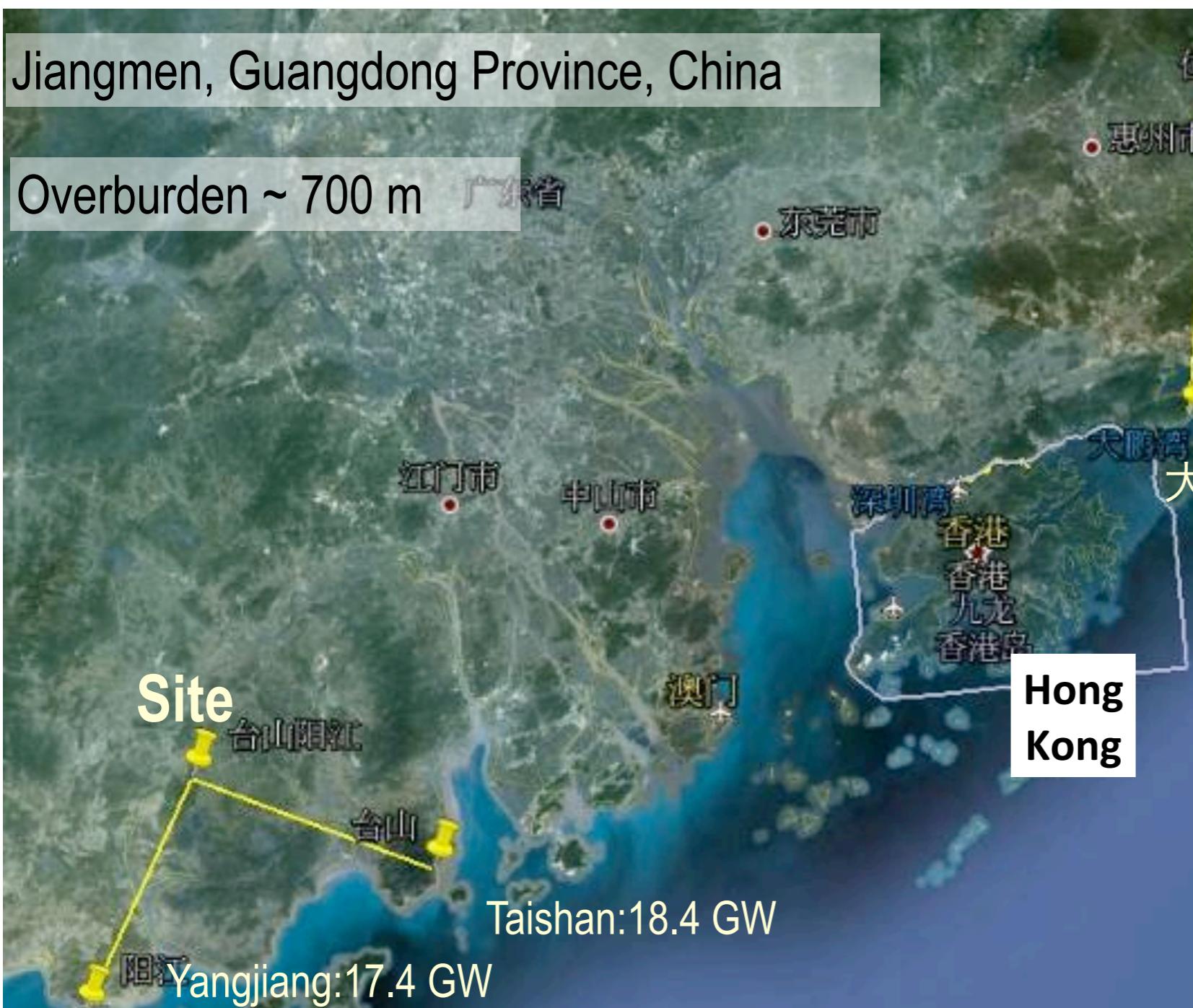
Rule out geo-reactor if $P > 0.3$ TW



Mass Hierarchy by reactors: JUNO

Note: RENO-50 is also under development

	Daya Bay	Yangjiang	Taishan
Status	running	Construction	construction
power/GW	17.4	17.4	18.4

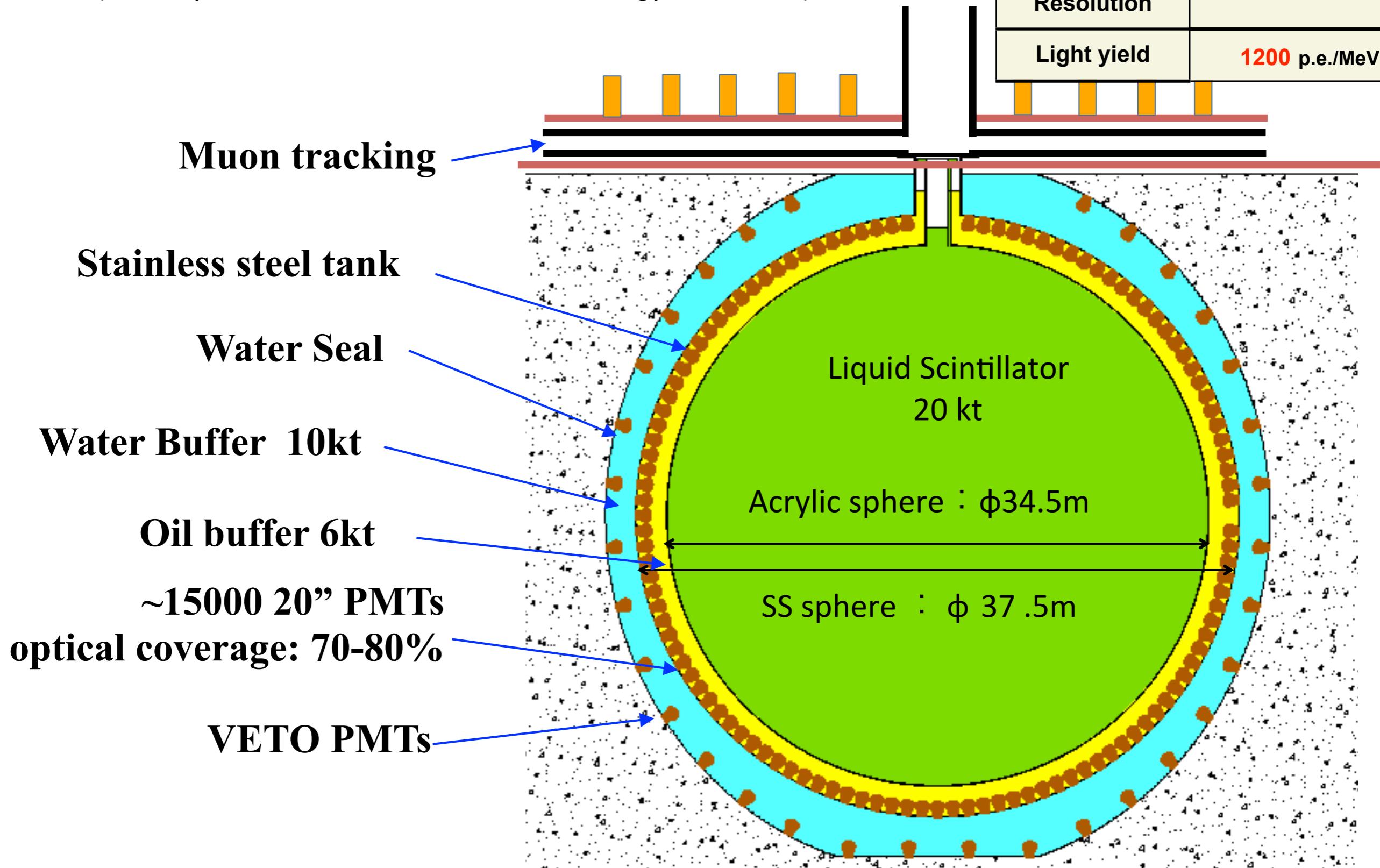


- Mass Hierarchy
- Mixing parameters
- Supernova neutrinos
- Geoneutrinos
- Sterile neutrinos

Detector Concept

(20kt liquid scintillator detector, ~3% energy resolution)

JUNO	
LS mass	20 kt
Energy Resolution	$3\%/\sqrt{E}$
Light yield	1200 p.e./MeV



Geo-neutrinos with JUNO

Notes: RENO-50
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development

- Some previously results:

- KamLAND:**

$40.0 \pm 10.5 \pm 11.5$ TNU

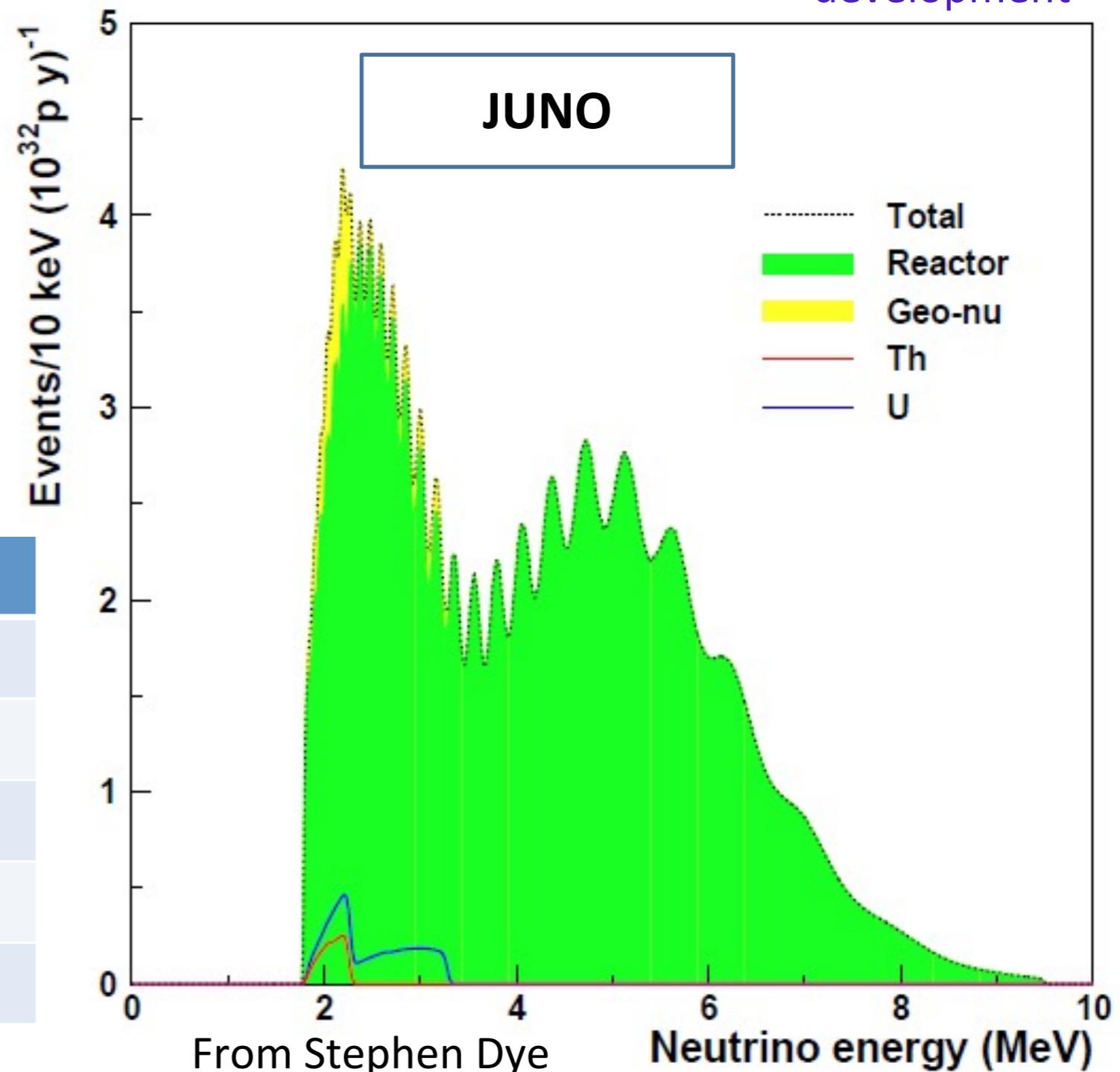
- Borexino:**

$64 \pm 25 \pm 2$ TNU

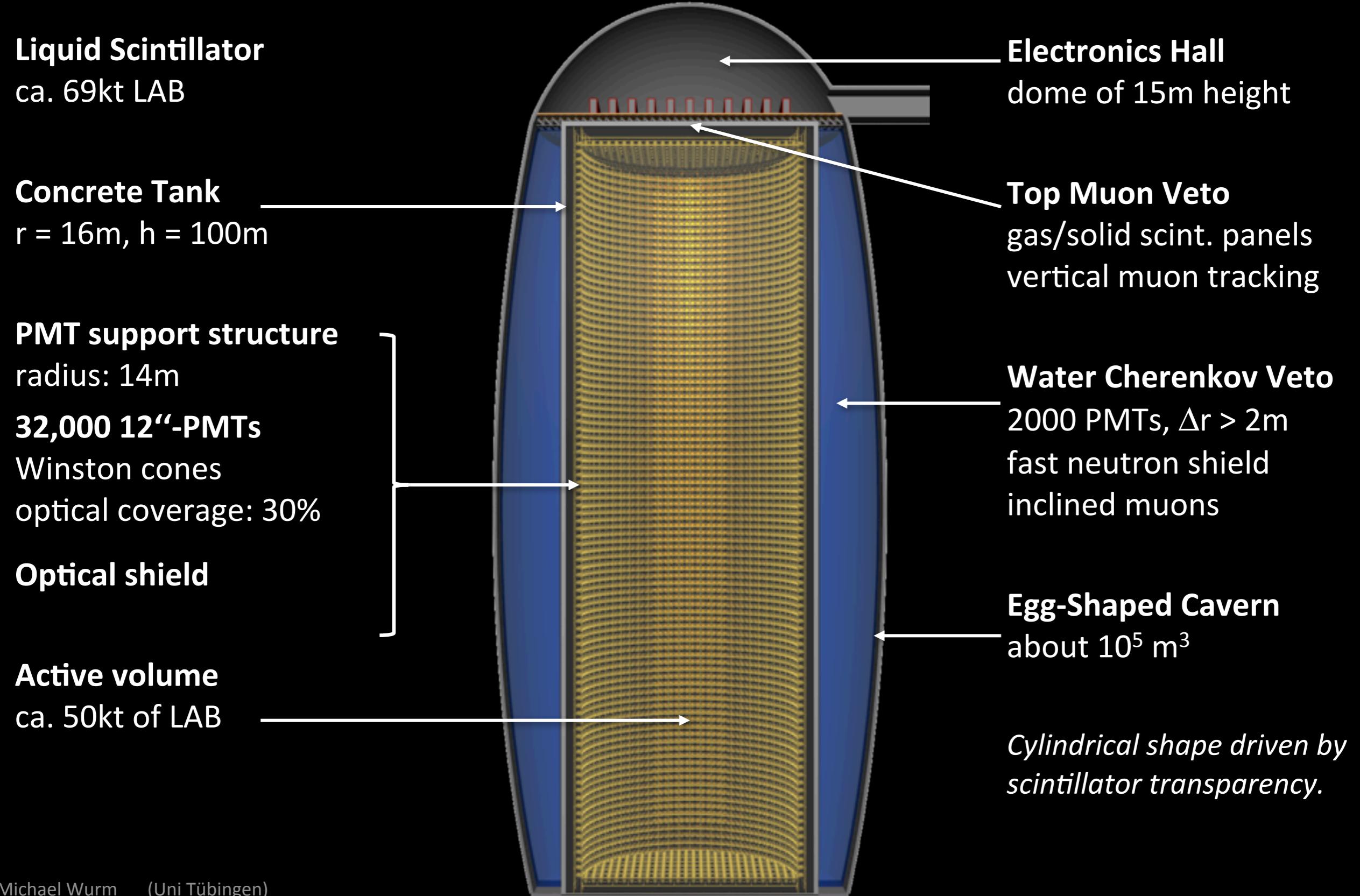
- JUNO:**

- Statistics: ~500 events/year
- Better systematic analysis

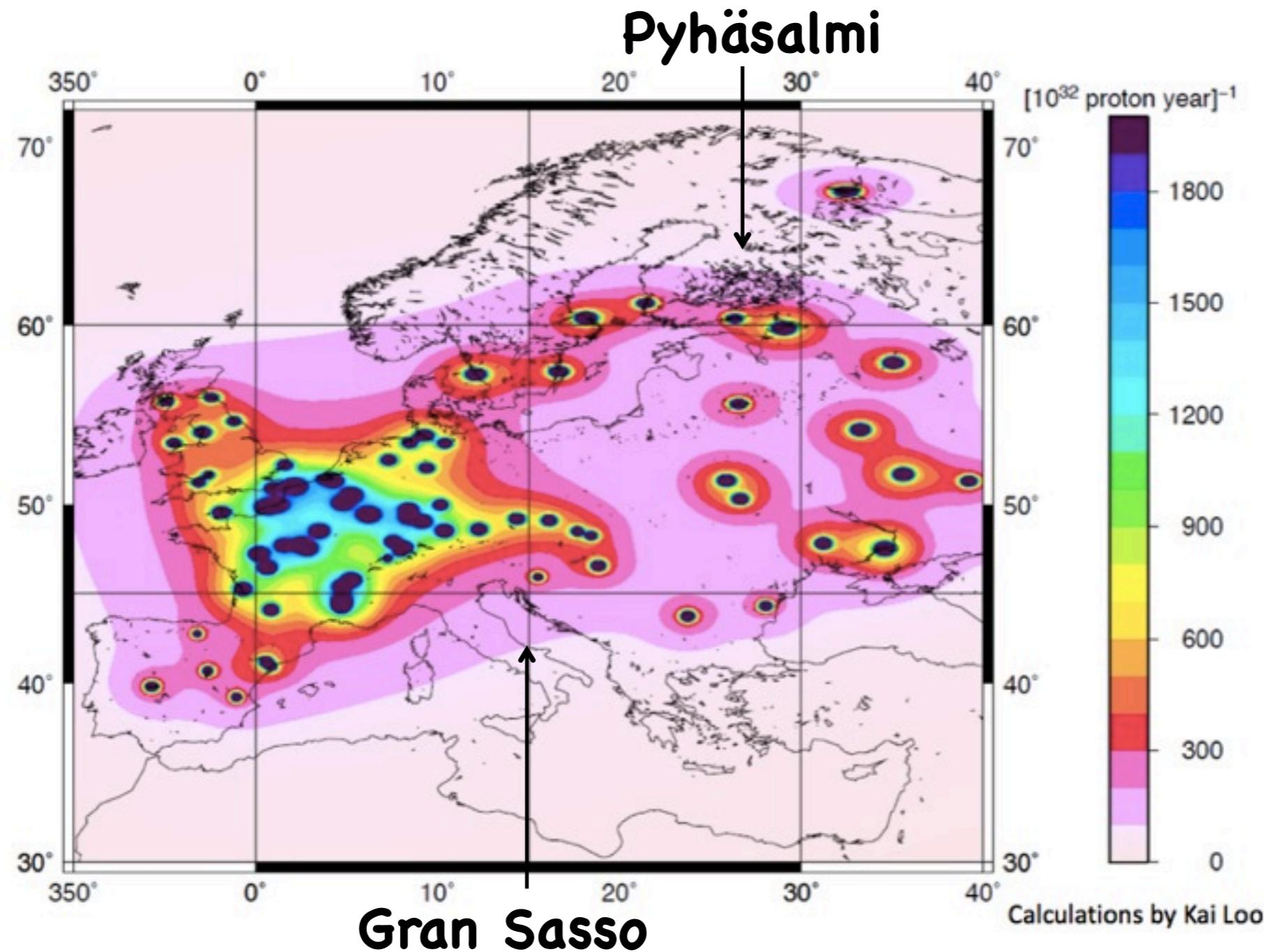
JUNO	Event per day
Acc.	<~1.2
$^9\text{Li}/^8\text{He}$	<~1
Fast n	~0.15
$^{13}\text{C}(\alpha, n)^{16}\text{O}$	<~2.2
Geo-neutrino	~1.3



LENA detector layout

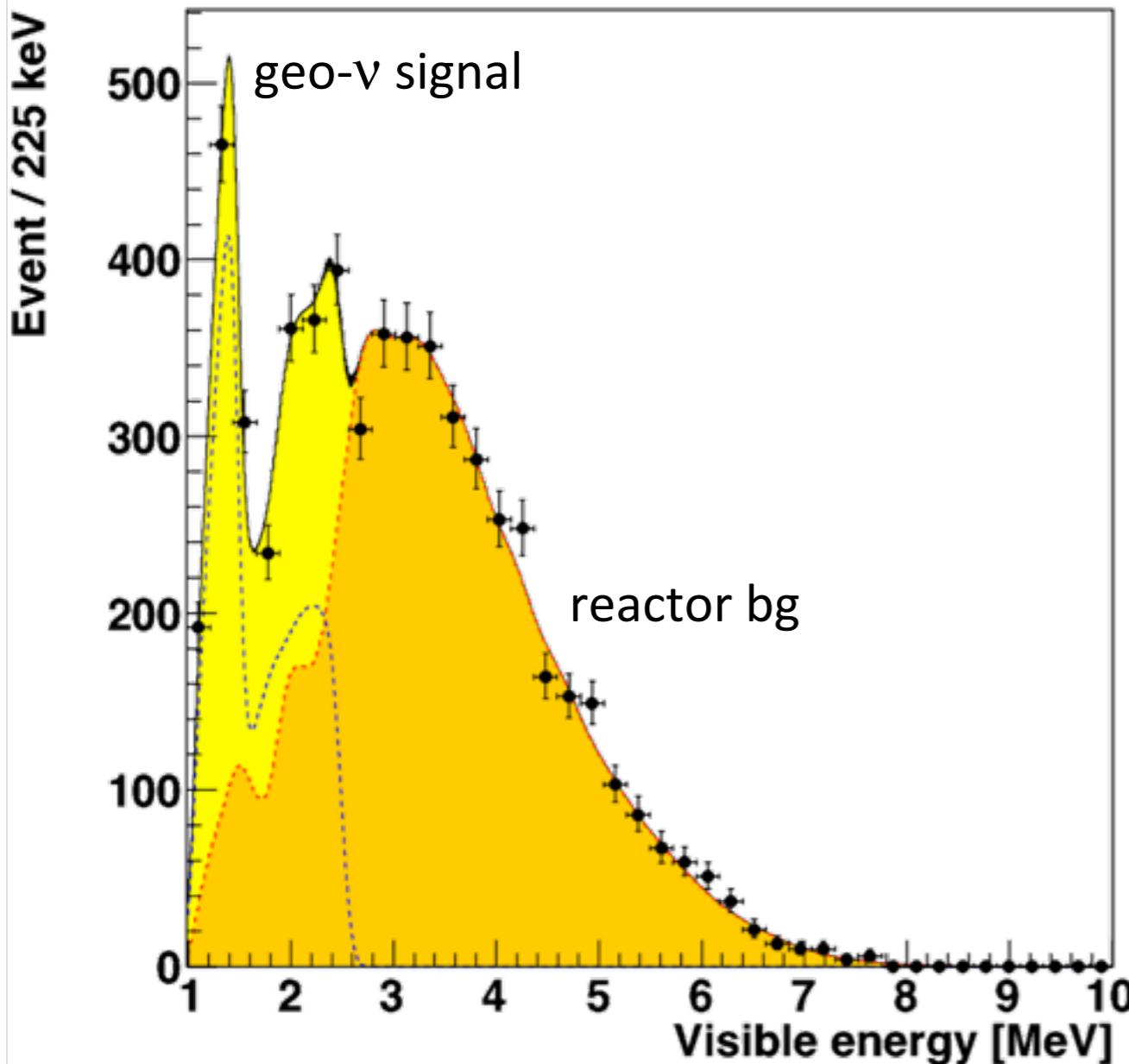


Reactor neutrino background map



→very good background conditions: $\sim 2 \times 10^3$ IBDs per year

Expected signal spectrum in LENA



prompt e^+ spectrum at Pyhäsalmi

- after 1 year (44kt)
- planned Finnish reactors included

Expected event numbers

after 1 year

■ Geoneutrinos:	1.5×10^3
■ Reactor ν 's:	2.2×10^3
■ below 3.3 MeV:	6.4×10^2
■ incl. planned Finnish reactors:	1.2×10^3

→ High-statistics

measurement

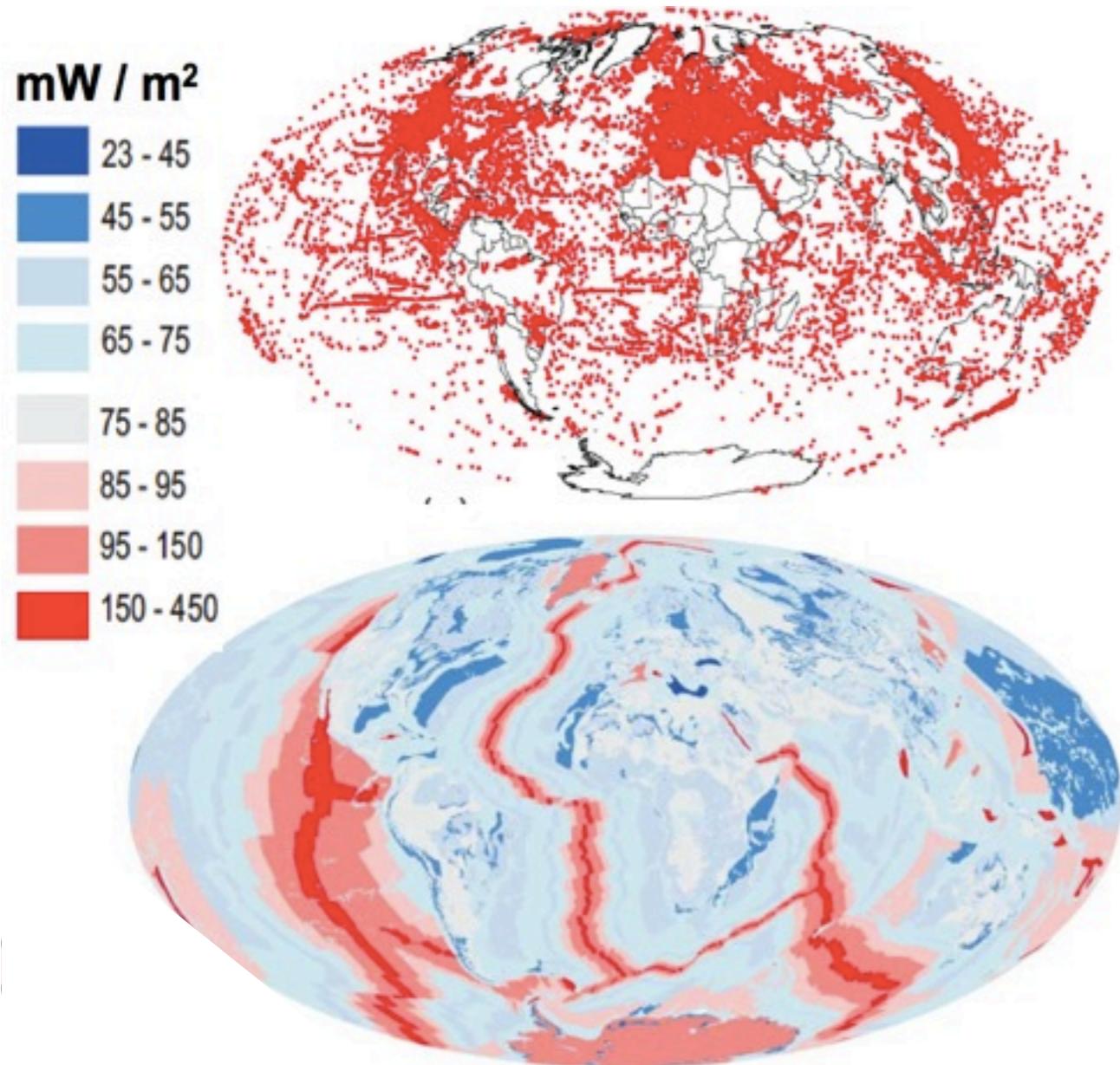
→ Signal-to-background
ratio of 2.3-1.3

for comparison:

KamLAND (2010) S:B ≈ 0.5

Borexino S:B ≈ 3

Precise determination of geoneutrino flux



Earth heat flow map

Mantovani (TAUP 2011)

Borehole measurements

→ **total thermal power** 46-31 TW

Bulk Silicate Earth models predict

→ **radiogenic heat** 20-31 TW

→ closely linked to total geo-v output

Accuracy for geo-v flux in LENA

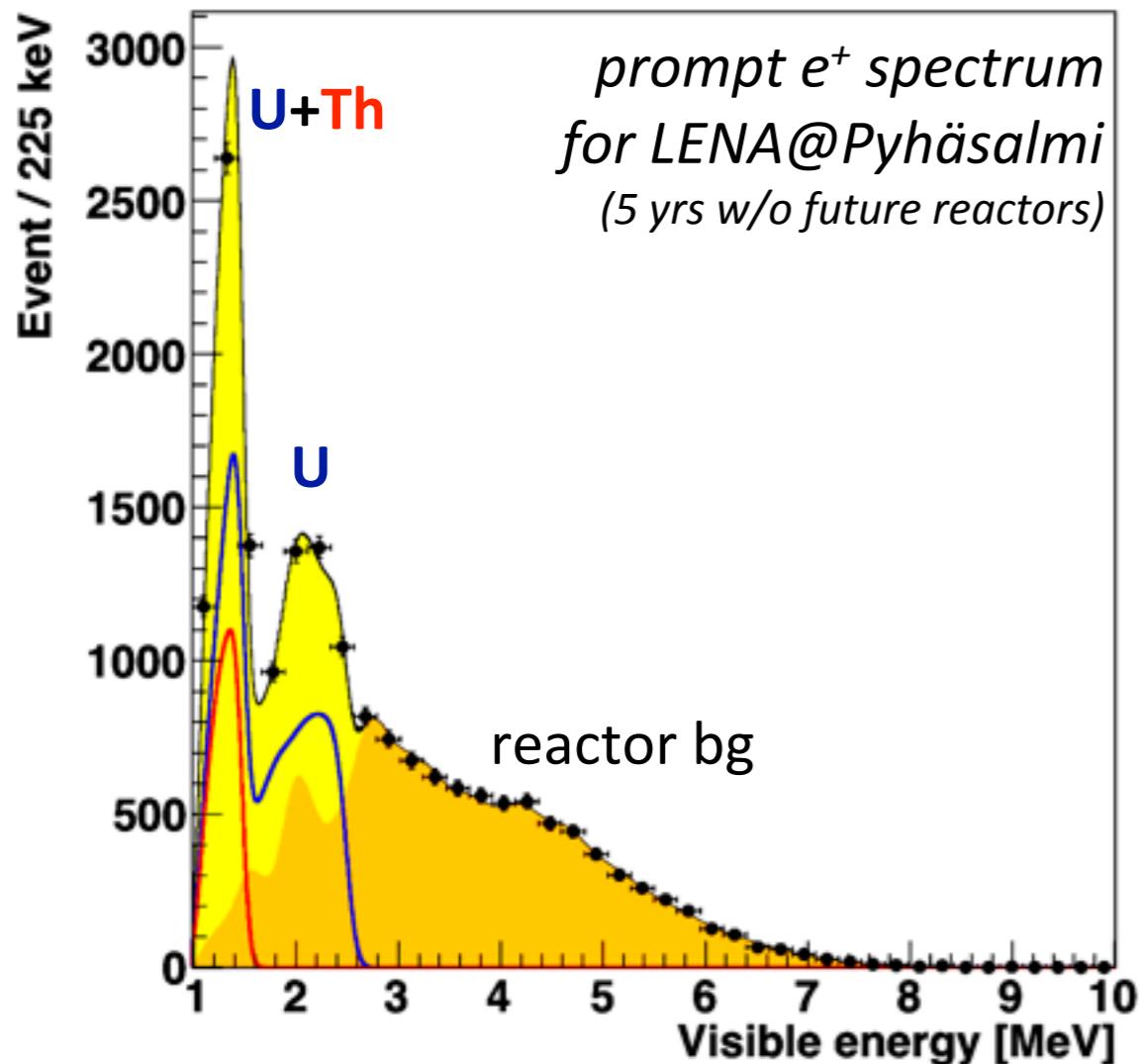
- after 1 year: 4%
- after 3 years: 2%
- after 10 years: 1%
- *current detectors:* 30-40%

→ precise input for Urey number

CAVEAT: (almost) no directionality

→ systematics from U/Th distribution

Measurement of Th/U ratio



→ ratio Th/U can be determined
from relative peak heights

Predicted Th/U ratio of mantle

- Turcotte & Schubert (2002) 4.0
- Anderson (2007) 4.0
- Palme & O'Neill (2003) 3.8
- Allegre et al. (1995) 3.9
- McDonough & Sun (1995) 3.9
- Lyubetskaya & Korenaga ('07) 3.7
- Javoy et al. (2010) 3.5

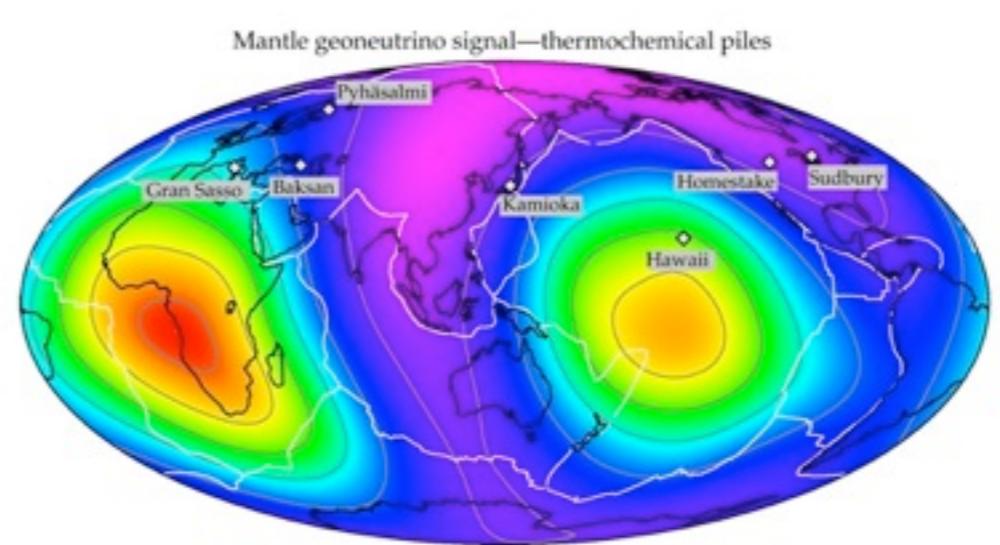
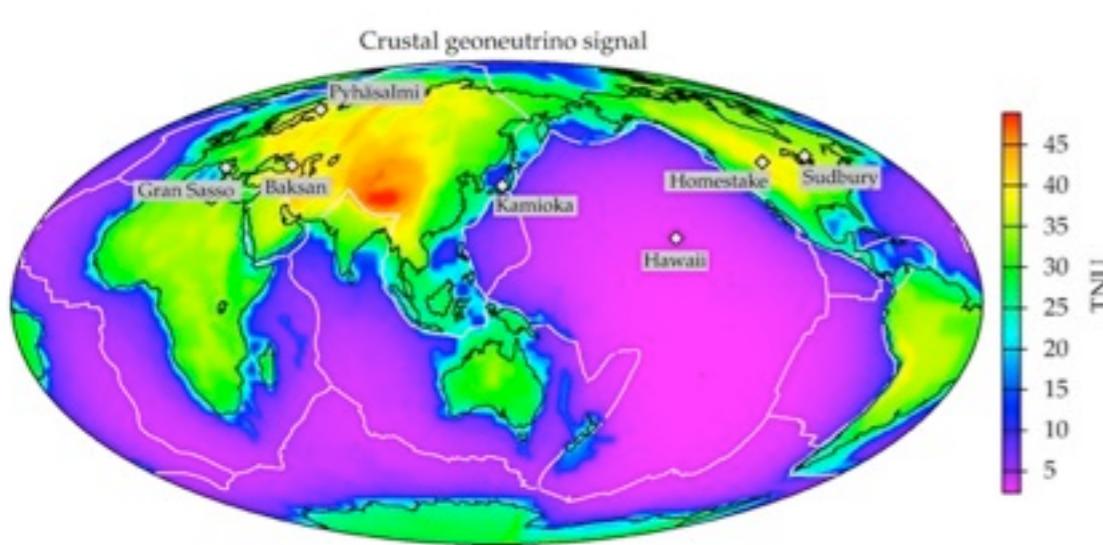
→ Ratio ranges from 3.5 to 4.0

Precision expected for LENA

- after 1 year: 17%
- after 3 years: 10%
- after 10 years: 5%

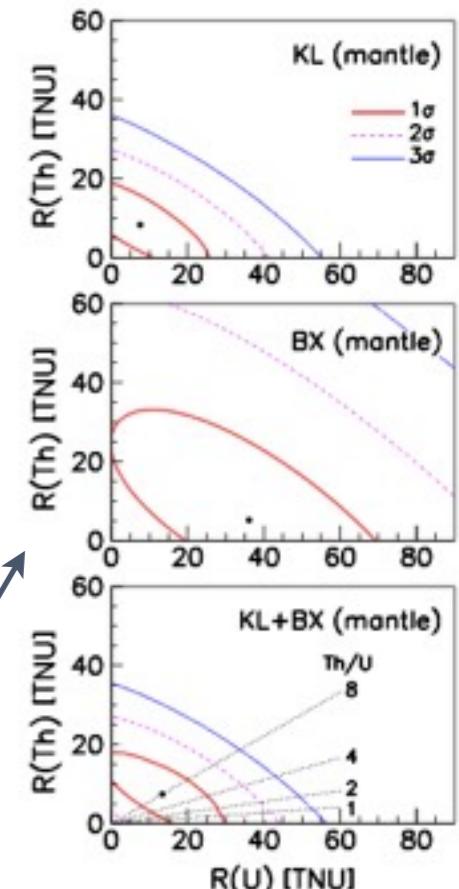
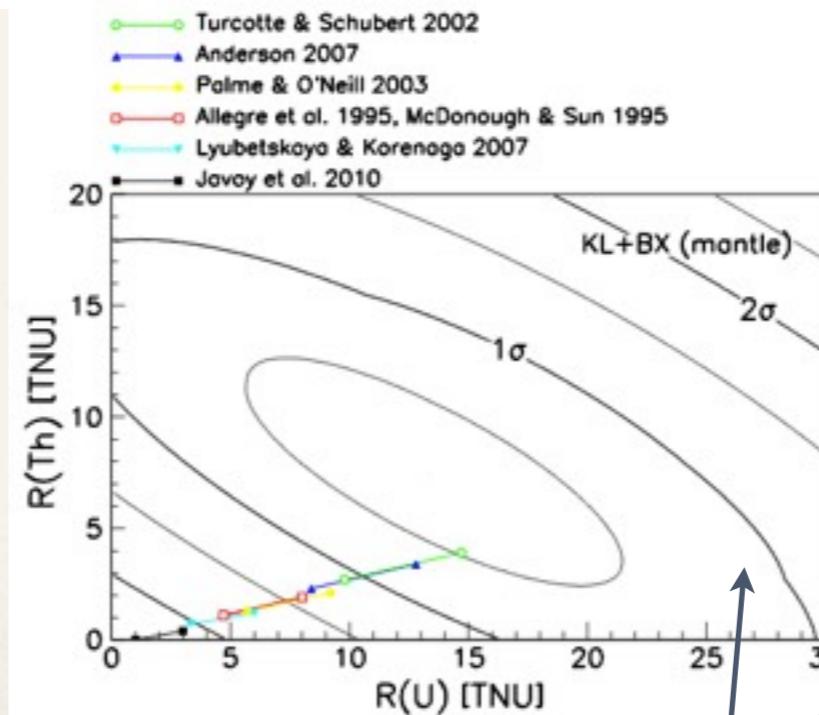
→ constrains or may even rule out
extreme geological models

All Around the World – Adding New Meaning to the Term “Global Analysis”



Šrámek, McDonough, Learned (2012)

Global analysis is already showing ability to constrain...wait until we have new geo-v data from 1-4 more sites around the world (with well-understood local geology).



- “within the reasonable assumption of site-independent mantle flux”

G. Fiorentini, G.L. Fogli, E. Lisi, F. Mantovani, A.M. Rotunno, arXiv:1204.1923v2

A Vision of the Distant Future: Geo- ν Experimental Goals

- * Directionallity?
 - * ${}^6\text{Li}$ -loaded liquid scintillator to localize forward-recoiling neutron (e.g. see Watanabe, Neutrino Geoscience 2010)
$$\bar{\nu}_e + p \rightarrow e^+ + n$$
$$n + {}^6\text{Li} \rightarrow \alpha + {}^3\text{He}$$
- * ${}^{40}\text{K}$ geo neutrino detection (maximum energy 1.311 MeV)?
 - * ${}^{106}\text{Cd}$ antineutrino capture with threshold 1.216 MeV (see Chen, Neutrino Geoscience 2005)
 - * delayed coincidence positron-positron!

